E. J. Bauschenberger

PROGRAM For 1956 TECHNICAL CONFERENCE FOR REA FIELD ENGINEERS (ELECTRIC)

January 16.- 20, 1956

Hotel Melbourne
Saint Louis, Missouri

The entire program is based on topics requested by REA Field Engineers. The program was developed by the Program Committee for Electric Engineers Technical Training: John F. Atkinson, Chairman, Hans Hoiberg, C. L. Hollister, W. E. Rushlow, R. P. Stokely and E. E. Warner.

REA

U. S. DEPARTMENT OF AGRICULTURE

RURAL ELECTRIFICATION ADMINISTRATION

MONDAY, JANUARY 16

Morning Session *

Colonial Room

E. E. Warner, Presiding

Economic Design of Primary Lines for Rural Distribution Systems	R. W. Schlie
Panel Discussion	~~G. T. Hall~~, Panel Chairman, J. H. Phillips and H. W. Thiesfeld

Afternoon Session

Colonial Room

G. H. Cole, Presiding

Maintenance Liability	Clark Reid and L. L. Huff
Discussion	G. K. Ditlow
Discussion	E. F. Wilson
Voltage Regulators	R. E. Horn, Allis-Chalmers Manufacturing Company
Discussion	R. W. Schlie

* Registration will begin at 9:00 A. M. The Monday Morning Session will start at 10:00 A. M.

TUESDAY, JANUARY 17

Morning Session

Union Electric Company Headquarters

R. P. Stokely, Presiding

Distribution Voltage - A Comparison of 12 KV and 4 KV Systems	S. F. Joyce and V. A. Gehrer, Union Electric Company
Discussion	E. A. Loetterle and H. R. Smith
Fault Protection for the Union Electric Subtransmission and Rural Distribution Circuits .	Ren Beatty and I. F. Krughoff, Union Electric Company
Discussion	L. B. Crann

Afternoon Session

Union Electric Company Headquarters

J. H. Rixse, Jr., Presiding

Transmission Line Maintenance	George W. Couch and M. G. Cox, Union Electric Company
Discussion	John G. Hieber
Load Dispatching in Union Electric System	J. K. Bryan, J. F. McLaughlin and L. A. Mollman, Union Electric Company
Discussion	W. E. Rushlow
Inspection of Load Dispatching Facilities	Union Electric Company

WEDNESDAY, JANUARY 18

Morning Session

Colonial Room

E. L. Arnn, Presiding

Service to Large Motor Loads . . . . H. W. Kelley

Discussion . . . . R. C. Holland

Discussion . . . . Wagner Electric Corporation

Afternoon Session

Wagner Electric Corporation

G. L. Woodworth, Presiding

Inspection of Motor Manufacturing and Other Facilities . . . . Wagner Electric Corporation

THURSDAY, JANUARY 19

Morning Session

Colonial Room

R. P. Stokely, Presiding

Load Trends on Rural Lines and Methods of Recording and Calculating Data	John Case
Discussion	R. W. Schlie and C. J. Waldron
System Improvement Planning	W. J. Hauck
Panel Discussion	E. D. Tatum Panel Chairman, J. B. Davis and G. F. Moon
Discussion	H. R. Smith
Discussion	E. R. Brown

Afternoon Session

James R. Kearney Corporation

G. H. Cole, Presiding

The Kearney High Power Test Substation	W. W. Olive, Jr., James R. Kearney Corporation
Inspection and Demonstration of High Power Test Substation * and Other Plant Facilities	James R. Kearney Corporation

* The High Current Test Substation is an outdoor facility. In view of the January weather it would appear advisable for participants to provide themselves with extra warm clothing.

FRIDAY, JANUARY 20

Morning Session

Colonial Room

J. E. O'Brien, Presiding

A Short Summary of the Problems of Nuclear Power . .	Wm. C. Morris
Discussion	J. E. O'Brien
Fiberglass Crossarms and Poles	W. R. Bailey, Gar Wood Industries, Incorporated
Discussion	John F. Atkinson

Conference will adjourn at 1:00 P. M.

NOTES

ECONOMIC DESIGN OF PRIMARY LINES FOR RURAL DISTRIBUTION SYSTEMS

By Roland W. Schlie
Distribution Systems Engineer
Electric Engineering Division

For Presentation at the 1956 Technical Conference for
REA Field Engineers, Saint Louis, Missouri
January 16 - 20, 1956

REA

U. S. DEPARTMENT OF AGRICULTURE

RURAL ELECTRIFICATION ADMINISTRATION

ABOUT THE CONFERENCE .... The purpose of the Annual Conference for REA Field Engineers is to provide a forum for the discussion of engineering matters concerned with rural electric systems. The objective is to make available to field engineers an opportunity to share views and experience with other engineers who have developed a high degree of experience and specialization in specific fields. Likewise, the objective is to provide the specialist engineer with an opportunity to share his views with those who are facing the practical daily engineering problems.

To assure freedom for the development of ideas which may serve to improve the engineering of rural electric systems, the authors of papers and discussions have been encouraged to explore new ideas and new techniques and to prepare papers which reflect their own engineering judgment and experience. Such an approach may develop ideas which deviate from industry practices and REA policies and procedures presently in effect. It should be recognized, however, that REA policies and procedures as set forth in REA bulletins are still applicable unless changed in the light of the ideas and experience which may result from such papers or discussions.

R G Zook

R. G. Zook
Assistant Administrator

ECONOMIC DESIGN OF PRIMARY LINES FOR RURAL DISTRIBUTION SYSTEMS

Roland W. Schlie

INTRODUCTION

It has often been stated that a distribution system design should have the lowest annual cost consistent with providing quality service to the consumers. In the selection of conductor sizes of primary lines for rural distribution systems, voltage drop limitations have often forced the selection of uneconomical conductor sizes. The application of voltage regulators provides an effective and practical means of maintaining adequate voltage on distribution lines. Voltage regulators permit more economic loading of primary line conductors.

Applying calculated economic loading limits to the design of primary lines is not as straightforward as applying voltage drop limits to the design of primary lines. It is the purpose of this paper to illustrate a practical method of calculating economic loading limits which can be effectively used for selecting conductor sizes.

THEORY

The total annual cost of a distribution line is equal to the sum of the fixed charges, and the demand and energy charges due to line losses. Fixed charges are assumed to be directly proportional to the cost of installed line. Demand charges are a function of peak losses and the demand charge rate. Energy charges are a function of total losses and the cost of energy. The relationships are plotted in Figure 1 for a single-phase, No. 4 ACSR line and for the assumed constants given in the Appendices. The annual cost is expressed in dollars per kilowatt mile and load is assumed the independent variable. Minimum annual cost results when the fixed charges equal the demand plus energy charges.

The relationship plotted in Figure 1 would be a useful design guide if it were assumed that the size of line is not a variable. This assumption, of course, is not true. Total annual costs are plotted in Figure 2 for two lines; a single-phase, No. 4 ACSR line and a single-phase, No. 2 ACSR line. There is a load for each line which results in a minimum annual cost. However, at a load level for which the No. 4 line has minimum annual cost, the No. 2 line has a lower annual cost. Therefore, the magnitude of load for which a specific line has a minimum annual cost is not significant.

There is a magnitude of load for which any two lines will have the same annual cost. This is illustrated by the intersection of the two curves plotted in Figure 2. It should be noted that at a load less than 125 kw, the No. 4 ACSR line has the lower annual cost. Also, at a load greater than 125 kw, the No. 2 ACSR line has the lower annual cost. These facts are significant and form the basis for the proposed method of calculating economic loading limits for selecting the conductor size for new lines.

The equation for solving the load at which two lines have equal annual cost is derived in Appendix I and is numbered equation (13). The calculations of the constants for equation (13) are given in Appendix IV.

Equation (9) of Appendix I is used to calculate the curves shown in Figures 3, 4, and 5. The solid portions of the curves for each conductor size represent the most economic loading for single-phase, "V"-phase and three-phase distribution lines. If the curves of Figures 3, 4, and 5 are plotted on common coordinates, a curve for the most economic loading of single-phase, "V"-phase or three-phase lines can be determined. The solid portions of the curves in Figure 6 are the most economic loading levels of single-phase, "V"-phase and three-phase distribution lines.

It should be noted from Figure 6 that "V"-phase lines are not economical for new lines. While this may not hold true for a specific system design having different construction costs and different demand and energy charges, it is generally true that "V"-phase lines tend to have a higher annual cost than do single-phase or three-phase lines.

SELECTION OF CONDUCTOR SIZES FOR NEW LINES

Graphic solutions to problems are frequently time consuming. While Figures 3, 4, 5, and 6 illustrate the loading limits to be used in designing new distribution lines, such a graphic solution is not practicable. The purpose of this paper is to illustrate a practical method of calculating loading limits to be used in the design of new lines. The proposed method follows.

Basic Data

Many of the variables of equation (13) of Appendix I must be assumed as constants for a specific system. The assumed constants used in this paper are given in Appendix IV. It is also necessary to estimate line construction costs. The costs used in this paper are given in Table I. Line characteristics are given in Table II.

Calculations of Loss Constant (J)

The loss constant is calculated as shown in Appendix IV. This constant (J) is assumed equal for all distribution lines used on the specific system for which loading limits are to be calculated.

Calculation of Equation Constants

Equation (13) of Appendix I is the equation by which loading limits are calculated. The equation constants are calculated as shown in Appendix IV.

Calculation of Loading Limits

The lowest capacity distribution line is first compared to the next largest capacity distribution line. For example:

Using equation (13) to compare single-phase No. 4 and No. 2 ACSR lines:

$$KW = 8.57\sqrt{\frac{C_d}{(R_s - R_l)}}$$

$$C_d = C_{No.2} - C_{No.4} = \$1320 - \$1150 = \$170$$

$$R_{s(No.4)} - R_{l(No.2)} = 2.5 - 1.7 = 0.8$$

$$KW = 125$$

A load of 125 kw is the maximum future root mean square (rms) load limit for a single-phase No. 4 ACSR line, and is the minimum future rms load limit for a single-phase, No. 2 ACSR line.

Additional calculations of the lowest capacity line compared to higher capacity lines are made. Results of these calculations are given in Table III. Calculations comparing a single-phase, No. 4 ACSR line to a single-phase, No. 2 ACSR line resulted in the lowest equal cost load, 125 kw. The single phase, No. 2 ACSR line is therefore the economical line for loads above 125 kw.

Identical calculations are made comparing a single-phase, No. 2 ACSR line to higher capacity lines. As given in Table III, calculations comparing a single-phase, No. 2 ACSR line to a three-phase, No. 4 ACSR line resulted in the lowest equal cost load, 201 kw. The three-phase, No. 4 ACSR line is therefore the economical line for loads above 201 kw.

These calculations are continued until the loading limits for all conductor sizes and combination of phasings to be used have been calculated. A summary of the results of these calculations are given in Table IV. Loading limits as given in Table IV are the future rms values. The rms values of future loads are not convenient values to use for the design of new lines. It is desirable to convert the rms future load levels to load levels which apply at the time when the line is to be constructed. This can be done by using Equation (8) given in Appendix II.

CONVERSION OF EXISTING LINES

Conversion should be made when the load on distribution line reaches a magnitude at which the savings in losses resulting from conversion are equal to the fixed charges of the cost to convert the line. Equation (14) of Appendix I has been derived to provide a method of calculating the load at which it becomes economical to convert the line.

The total annual cost of a single-phase, No. 4 ACSR line and of a three-phase, No. 4 ACSR line converted from a single-phase, No. 4 ACSR line is plotted in Figure 7. The two curves intersect. At a load less than 187 kw, the line should be maintained in service. At a load greater than 187 kw, the line should be converted.

In illustrating the calculations for determining the economic conversion loads, it is assumed that the equation constants have been calculated as illustrated in Appendix IV. It is also assumed that the costs of conversion for the various proposed conversions have been estimated. The conversion costs used in this paper are given in Table V.

Economic conversion loads for single-phase, "V"-phase and three-phase, No. 4 and No. 2 ACSR lines have been calculated and are given in Table VI. Following is one sample calculation.

Using equation (14) of Appendix I for single-phase to three-phase conversion:

$$KW = 14.8\sqrt{\frac{C_c}{(3R_e - R_n)}}$$

$$C_{c(\text{No.}4/1\phi\text{ to No.}4/3\phi)} = \$840$$

$$R_{n(No.4/3\emptyset)} = 2.2$$

$$3\ R_{e(No.4/1\emptyset)} = 7.5$$

$$KW = 187$$

A load of 187 kw should be reached before the line is converted.

A calculation should be made for each proposed conversion. The calculation resulting in the lowest economic conversion load identifies the economic conversion. Table VII gives the economic conversion loads.

It should be noted from Table VI that single-phase to "V"-phase conversion is but little better economically than single-phase to three-phase conversion. For example, single-phase to "V"-phase conversion of No. 4 ACSR conductor should be made when load reaches 183 kw. However, conversion from "V"-phase to three-phase of No. 4 ACSR conductor should be made when load reaches 219 kw. This indicates that the converted "V"-phase line would only be economical between 183 kw and 219 kw. Because of the narrow economic load range, conversion from single-phase to "V"-phase is not generally recommended.

Based on the results tabulated in Table VI, conversion involving a change in conductor size is rarely economical and therefore is not recommended. Also, conversion of three-phase lines does not appear economical. For example, the cost of converting a mile of three-phase, No. 4 ACSR line to a three-phase, No. 1/0 line is estimated to be $2400. Conversion would approximately double the capacity of the line. The cost of the No. 4 ACSR line plus the cost of conversion is $4250. A new No. 1/0 ACSR line would cost $2780. Conversion represents a 65% higher cost to obtain the capacity of a No. 1/0 ACSR line. The above indicates that express feeders, parallel feeders or new sources of supply should be recommended in lieu of converting three-phase lines.

CONCLUSIONS

Applying economic loading limits will facilitate designing a more economic system.

Large uneconomical conductor sizes should not be used to reduce voltage drop. Circuits should be shortened by adding additional sources of supply. Voltage regulators should be employed to within their practical limits of operation.

"V"-phase lines should be discouraged for new construction and for conversion.

Circuits should be shortened by adding additional sources of supply rather than making conversions involving a change of conductor size.

APPENDIX I

DERIVATIONS OF BASIC EQUATIONS

The basic equation for total annual cost may be written as follows:

$$T = F + D + E \qquad (1)$$

where:

T = total annual cost expressed in \$/mile
F = annual fixed charges expressed in \$/mile
D = annual demand charges expressed in \$/mile
E = annual energy charges expressed in \$/mile

The equations for fixed, demand and energy charges may be written as follows:

$$F = CA \text{ expressed in \$/mile of line} \tag{2}$$
$$D = I^2R(.012)MNP \text{ expressed in \$/mile of line} \tag{3}$$
$$E = I^2R(8.76)LHP \text{ expressed in \$/mile of line} \tag{4}$$

where:

C = Cost per mile of line expressed in \$/mile. The cost of transformers, secondary services, overcurrent protective devices, lightning protection devices, right-of-way clearing and engineering fees should not be included in the cost.

A = Annual fixed charge rate expressed as a decimal. The rate is the total of the following annual charges: Interest, Depreciation, Insurance, Taxes, Operations and Maintenance.

I = RMS magnitude of future load expressed in amperes per phase.

R = Resistance expressed in ohms per phase per mile.

P = Number of phases.

M = Demand charge expressed in \$/kw/mo.

L = Energy charge expressed in \$/kwh.

H = Yearly loss factor expressed as a decimal, "H" is equal to $.84(\text{Load Factor})^2 + .16(\text{Load Factor})$

N = Yearly demand factor expressed as a decimal, "N" is equal to the average monthly kw demand divided by the peak monthly demand.

Substituting equations (2), (3), and (4) in equation (1) gives the following:

$$T = CA + I^2RP(.012MN + 8.76LH) \tag{5}$$

The expression $(.012MN + 8.76LH)$ may be called the system loss constant and is designated by the letter J. The loss constant is assumed equal for all conductor sizes used on the system. For simplicity, equation (5) is written as follows:

$$T = CA + I^2RPJ \tag{6}$$

Load is normally expressed in kilowatts rather than amperes.

$$I^2 = \frac{(KW)^2}{(KV)^2(\cos\theta)^2P^2} \tag{7}$$

Substituting equation (7) in equation (6) gives the following:

$$T = CA + \frac{(KW)^2 RJ}{(VS)^2 (\cos\theta)^2 P} \tag{8}$$

From equation (8) it is possible to derive an equation from which the most economical load may be calculated.

Divide each term in equation (8) by KW.

$$\frac{T}{(KW)} = \frac{CA}{(KW)} + \frac{(KW)JR}{(KV)^2 (\cos\theta)^2 P} \tag{9}$$

Take the derivative of T/KW with respect to KW.

$$\frac{d(T/KW)}{d(KW)} = -\frac{CA}{(KW)^2} + \frac{JR}{(KV)^2 (\cos\theta)^2 P} \tag{10}$$

When d(T/KW)/d(KW) equals zero, T/KW is a minimum, therefore:

$$(KW)^2 = \frac{CA(\cos\theta)^2 (KV)^2 P}{JR} \tag{11}$$

Equations (8) and (11) are useful for calculations involving a specific line. When it is desirable to compare different lines, additional equations can be derived which are more useful. Assume that:

T_s = the total annual cost to install and operate the line of smaller capacity.

T_l = the total annual cost to install and operate the line of larger capacity.

$T_l - T_s$ = the difference in total annual cost to install and operate the larger capacity line.

s - used as a subscript, refers to the smaller capacity line.

l - used as a subscript, refers to the larger capacity line.

Also assume that:

$(KW)_l = (KW)_s$, $(KV)_l = (KV)_s$, $(\cos\theta)_l = (\cos\theta)_s$,

$J_l = J_s$ and $A_l = A_s$

then:

$$T_l = AC_l + \frac{(KW)^2 R_l J}{(KV)^2 (\cos\theta)^2 P_l}$$

$$T_s = AC_s + \frac{(KW)^2 R_s J}{(KV)^2 (\cos\theta)^2 P_s}$$

$$T_l - T_s = A(C_l - C_s) + \frac{(KW)^2 J}{(KV)^2 (\cos\theta)^2} (R_l/P_l - R_s/P_s)$$

Let $(T_l - T_s)$ be designated T_d and $(C_l - C_s)$ be designated C_d, then:

$$T_d = AC_d + \frac{(KW)^2 J}{(KV)^2 (\cos \theta)^2} (R_l/P_l - R_s/P_s) \qquad (12)$$

If T_d is positive, the smaller conductor size would have the lower annual cost.

If T_d is negative, the larger conductor size would have the lower annual cost.

If T_d is zero, both conductor sizes would have the same annual cost.

It is often desirable to know the load level at which two conductor sizes would have the same annual cost. If T_d is assumed to be equal to zero, then:

$$(KW)^2 = \frac{AC_d (KV)^2 (\cos \theta)^2}{J(R_s/P_s - R_l/P_l)} \qquad (13)$$

The magnitude of KW as calculated from equation (13) is the rms value of future load for which the annual cost is equal for two different conductor sizes.

Equation (13) is used to compare two new lines. By a similar method of derivation an equation for comparing existing lines to converted lines may be derived. Equation (14) is the equation in final form.

$$(KW)^2 = \frac{AC_c (KV)^2 (\cos \theta)^2}{J(R_e/P_e - R_n/P_n)} \qquad (14)$$

where: C_c = the cost of removing obsolete portions of the existing line minus the salvage value of the obsolete portions plus the installed cost of additions to the existing line.

R_n = Resistance of the new line expressed in ohms per mile.

P_n = Number of phases of the new line.

R_e = Resistance of the existing line expressed in ohms per mile.

P_e = Number of phases of the existing line.

The magnitude of KW as calculated from equation (14) is the load for which the annual costs are equal for the existing line and the new line. When a line approaches the load calculated from equation (14) it is economical to make the conversion. If present load is less than the calculated load, conversion would increase annual cost. If present load is greater than the calculated load, conversion would decrease annual cost.

APPENDIX II

FUTURE LOADS

The basic equations derived in Appendix I are used to calculate the future rms load level of KW for which two different lines would have the same total annual cost. In order to express the calculated rms load level in terms of the present load level, the load growth of the system and of the lines must be estimated. The equation for system load growth may be written as follows:

$$KW_f = KW_p (1 + G)^n \qquad (1)$$

where: KW_p = The present KW demand per consumer.

KW_f = The future KW demand per consumer.

G = Rate of load growth expressed as a decimal.

n = The number of years.

The equation for the future rms load level may be written as follows:

$$KW_{RMS} = \sqrt{\text{Average } (KW_f)^2} \qquad (2)$$

The equation for the "Average $(KW_f)^2$" may be written as follows:

$$\text{Average } (KW_f)^2 = \frac{\int_o^n (KW_f)^2 \, dn}{n} \qquad (3)$$

Integrating equation (3) between zero and "n" gives equation (4).

$$\text{Average } (KW_f)^2 = (KW_p)^2 \frac{(1 + G)^{2n} - 1}{\log_e (1 + G)^{2n}} \qquad (4)$$

Rewriting equation (1) as,

$$(1 + G)^{2n} = \frac{(KW_f)^2}{(KW_p)^2} \qquad (5)$$

letting,

$$a = \frac{KW_f}{KW_p} \qquad (6)$$

and substituting in equation (4) gives the following:

$$\text{Average } (KW_f)^2 = (KW_p)^2 \frac{a^2 - 1}{\log_e (a)^2}$$

$$KW_{RMS} = KW_p \sqrt{\frac{a^2 - 1}{\log_e (a)^2}} \qquad (7)$$

System load growth and distribution line load growth are rarely the same. This is true because the distribution line is almost always modified during its physical life. For example, lines are converted from single-phase lines to multiple-phase lines or three-phase lines are shortened by adding new sources of supply. It is therefore necessary to estimate the most economical and logical development of load growth on a distribution line. Figures 8 and 9 illustrate two identical load growth patterns resulting from two different developments of feeder capacity. Preliminary studies indicate these two developments of feeder capacity to be the most economical and logical methods. Further study may reveal alternates of equal worth. The resulting rms loads are expected to be very close to value calculated from Figures 8 and 9.

The future rms load level as calculated from Figures 8 and 9 is equal to 2.38 times the present load. This relationship is used in converting the future rms load limits as calculated from equation (13) of Appendix I to present load limits. Present load (the load at the time when the line is to be constructed) is calculated from the following equation.

$$KW_p = 0.42\ KW_{RMS} \tag{8}$$

APPENDIX III

COST DATA AND LINE CHARACTERISTICS

The cost estimates for the construction of new line must include all costs which vary as a function of the choice in distribution line design. Table I contains the cost data used in calculating the curves and tables included in this paper. They are costs which vary as a function of changing conductor size or phasing.

The cost estimates for the conversion of an existing line to a line of greater capacity include the cost of removing obsolete portions of the existing line minus the salvage value of the obsolete portions plus the installed costs of additions to the existing line. Table V contains the cost data used in calculating the curves and tables included in this paper.

Characteristics of primary lines of REA standard design are given in Table II. The values given are consistent with the accuracy of other basic data used in making economic calculations.

APPENDIX IV

CALCULATION OF CONSTANTS

Assumed Constants:		Loss Constant (J)
Fixed Charge Rate (A)	= .07	$J = .012\ MN + 8.76\ LH$
Demand Charge (M)	= \$1.61/kw	$H = .84(LF)^2 + .16\ LF$
Energy Charge (L)	= \$ .013/kwh	$H = (.84)(.16) + .16\ (.4)$
Load Factor (LF)	= .40	$H = .1984$
Power Factor ($\cos\theta$)	= .90	$J = (.012)(1.61)(.9) + (8.76)(.013)(.1984)$
Line to Neutral Voltage (kv)	= 7.2	$J = .01739 + .02259$
Demand Factor (N)	= .90	$J = .04$

Equation (13):

$$KW^2 = \frac{AC_d\ (KV)^2(\cos\theta)^2}{J(R_s/P_s - R_1/P_1)}$$

$$KW^2 = \frac{.07\ (7.2)^2(.9)^2\ C_d}{.04\ (R_s/P_s - R_1/P_1)}$$

$$KW^2 = 73.5\ \frac{C_d}{(R_s/P_s - R_1/P_1)}$$

For Single-Phase Vs Single-Phase Lines $$KW = 8.57\sqrt{\frac{C_d}{R_s - R_l}}$$

For Single-Phase Vs "V"-Phase Lines $$KW = 12.1\sqrt{\frac{C_d}{2R_s - R_l}}$$

For Single-Phase Vs Three-Phase Lines $$KW = 14.8\sqrt{\frac{C_d}{3R_s - R_l}}$$

For "V"-Phase Vs "V"-Phase Lines $$KW = 12.1\sqrt{\frac{C_d}{R_s - R_l}}$$

For "V"-Phase Vs Three-Phase Lines $$KW = 21.0\sqrt{\frac{C_d}{3R_s - 2R_l}}$$

For Three-Phase Vs Three-Phase Lines $$KW = 14.8\sqrt{\frac{C_d}{R_s - R_l}}$$

Equation (14)

The constants for equation (14) are the same as for equation (13).

REFERENCES

1. Effect of Load Growth on Economic Conductor Size, H. H. Hunt. AIEE Transactions, Power Apparatus and Systems No. 14, 1954, pp. 1049-54.

2. Economic Conductor Sizes for Overhead Distribution System, Arthur T. Green. Niagara Mohawk Power Corporation, Buffalo, New York, March 15, 1952.

3. Power Loss in Conductors, REA Engineering Memorandum 182R2, August 31, 1951.

4. Electrical Distribution Engineering (book), H. P. Seelye. McGraw-Hill Book Company, Inc., New York, N. Y., 1930, pp. 642-52.

TABLE I

DISTRIBUTION LINE CONSTRUCTION COST FOR ACSR CONDUCTORS

Conductor Size ACSR	Costs In Dollars Per Mile		
	Single Phase	"V"-Phase	Three Phase
4	1150	1580	1850
2	1320	1850	2180
1/0	1720	2330	2780
2/0	1920	2620	3140
3/0	2190	3000	3560

TABLE II

DISTRIBUTION LINE IMPEDANCE

Conductor Size ACSR	Per Phase Ohms Per Mile								
	Single Phase			"V"-Phase			Three Phase		
	R	X	Z	R	X	Z	R	X	Z
4	2.5	1.4	2.9	2.5	1.4	2.9	2.2	.80	2.3
2	1.7	1.3	2.1	1.7	1.3	2.1	1.4	.78	1.6
1/0	1.1	1.2	1.6	1.1	1.2	1.6	.89	.77	1.2
2/0	.88	1.1	1.4	.88	1.1	1.4	.70	.74	1.0
3/0	.71	1.0	1.2	.71	1.0	1.2	.56	.73	.92

TABLE III

COMPARISON OF NEW LINES

Line Comparison	Equal Cost Load (Future RMS KW)	Line Comparison	Equal Cost Load (Future RMS KW)
1Ø#4 or 1Ø#2	125	1Ø#2 or 3Ø#4	201
1Ø#4 or VØ#4	159	1Ø#2 or 3Ø#2	226
1Ø#4 or VØ#2	176	1Ø#2 or 3Ø#1/0	276
1Ø#4 or 3Ø#4	176	3Ø#4 or 3Ø#2	302
1Ø#4 or 3Ø#2	159		
1Ø#2 or 1Ø#1/0	221	3Ø#2 or 3Ø#1/0	509
1Ø#2 or VØ#4	206		
1Ø#2 or VØ#2	214	3Ø#1/0 or 3Ø#2/0	646
1Ø#2 or VØ#1/0	254	3Ø#2/0 or 3Ø#3/0	813

TABLE IV

ECONOMIC FUTURE RMS LOAD LIMITS

Line Description		Min. Load (Kilowatts)	Max. Load (Kilowatts)
1∅#4	ACSR	---	125
1∅#2	ACSR	125	201
3∅#4	ACSR	201	302
3∅#2	ACSR	301	509
3∅#1/0	ACSR	509	646
3∅#2/0	ACSR	646	813
3∅#3/0	ACSR	813	---

TABLE V

DISTRIBUTION LINE CONVERSION COST FOR ACSR CONDUCTORS

Conversion Description	Cost in $/Mile
1∅#4 to V∅#4	570
1∅#4 to V∅#2	1320
1∅#4 to V∅#1/0	2060
1∅#4 to 3∅#4	840
1∅#4 to 3∅#2	1610
1∅#4 to 3∅#1/0	2410
1∅#2 to V∅#2	600
1∅#2 to V∅#1/0	1120
1∅#2 to V∅#2/0	1500
1∅#2 to 3∅#2	1020
1∅#2 to 3∅#1/0	1530
1∅#2 to 3∅#2/0	1980

Conversion Description	Cost in $/Mile
V∅#4 to 3∅#4	340
V∅#4 to 3∅#2	1650
V∅#4 to 3∅#1/0	2170
V∅#2 to 3∅#2	500
V∅#2 to 3∅#1/0	1100
V∅#2 to 3∅#2/0	1570
3∅#4 to 3∅#2	1890
3∅#4 to 3∅#1/0	2400
3∅#2 to 3∅#1/0	750
3∅#2 to 3∅#2/0	1210

TABLE VI

ECONOMIC CONVERSION LOADS

Conversion	Wire Size (ACSR)	Economic Conversion Load (Kilowatts)
1Ø to VØ	#4 to #4	183
1Ø to VØ	#4 to #2	242
1Ø to VØ	#4 to #1/0	278
1Ø to VØ	#2 to #2	228
1Ø to VØ	#2 to #1/0	267
1Ø to VØ	#2 to #2/0	296
1Ø to 3Ø	#4 to #4	187
1Ø to 3Ø	#4 to #2	241
1Ø to 3Ø	#4 to #1/0	284
1Ø to 3Ø	#2 to #2	247
1Ø to 3Ø	#2 to #1/0	283
1Ø to 3Ø	#2 to #2/0	315

Conversion	Wire Size (ACSR)	Economic Conversion Load (Kilowatts)
VØ to 3Ø	#4 to #4	219
VØ to 3Ø	#4 to #2	394
VØ to 3Ø	#4 to #1/0	409
VØ to 3Ø	#2 to #2	311
VØ to 3Ø	#2 to #1/0	382
VØ to 3Ø	#2 to #2/0	433
3Ø to 3Ø	#4 to #2	722
3Ø to 3Ø	#4 to #1/0	636
3Ø to 3Ø	#2 to #1/0	570
3Ø to 3Ø	#2 to #2/0	617

TABLE VII

MOST ECONOMIC CONVERSIONS

Conversion	Wire Size (ACSR)	Economic Conversion Load (Kilowatts)
1Ø - VØ	#4 to #4	183
1Ø - VØ	#2 to #2	228
1Ø - 3Ø	#4 to #4	187
1Ø - 3Ø	#2 to #2	247
VØ - 3Ø	#4 to #4	219
VØ - 3Ø	#2 to #2	311
3Ø - 3Ø	#4 to #1/0	636
3Ø - 3Ø	#2 to #1/0	570

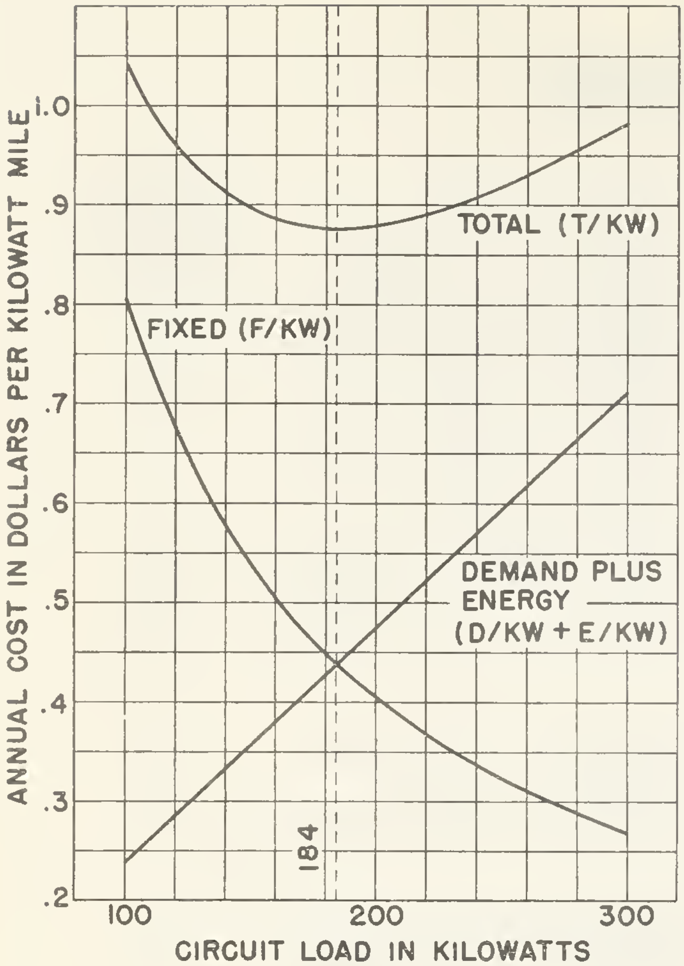

Fig. 1. Annual Cost of a Single-Phase No. 4 ACSR Rural Distribution Line, 7.2 KV.

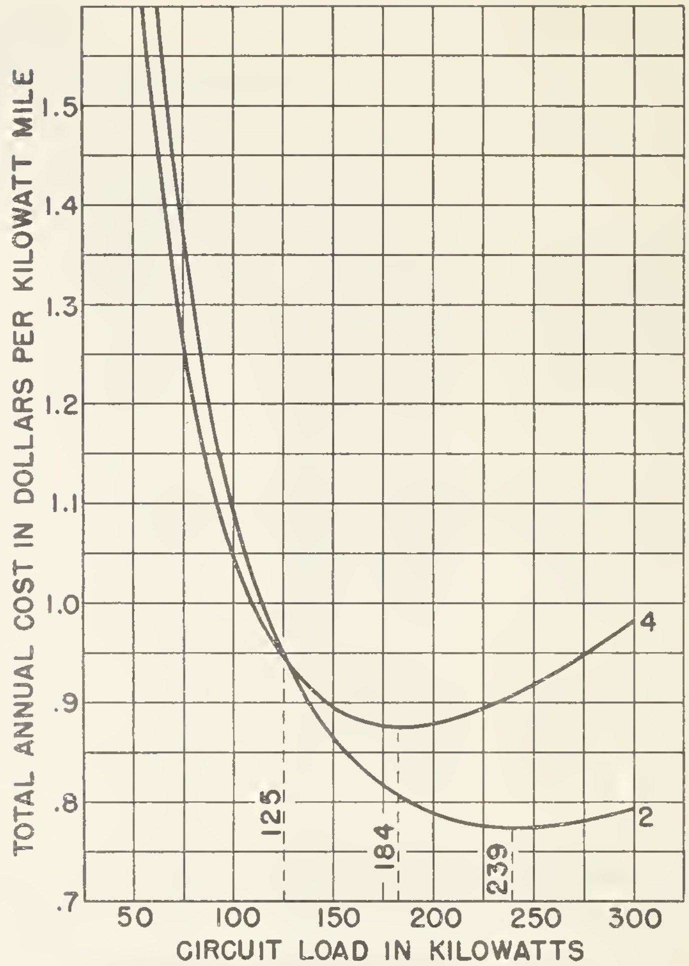

Fig. 2. Annual Cost of a Single-Phase No. 4 and No. 2 ACSR Rural Distribution Line, 7.2 KV.

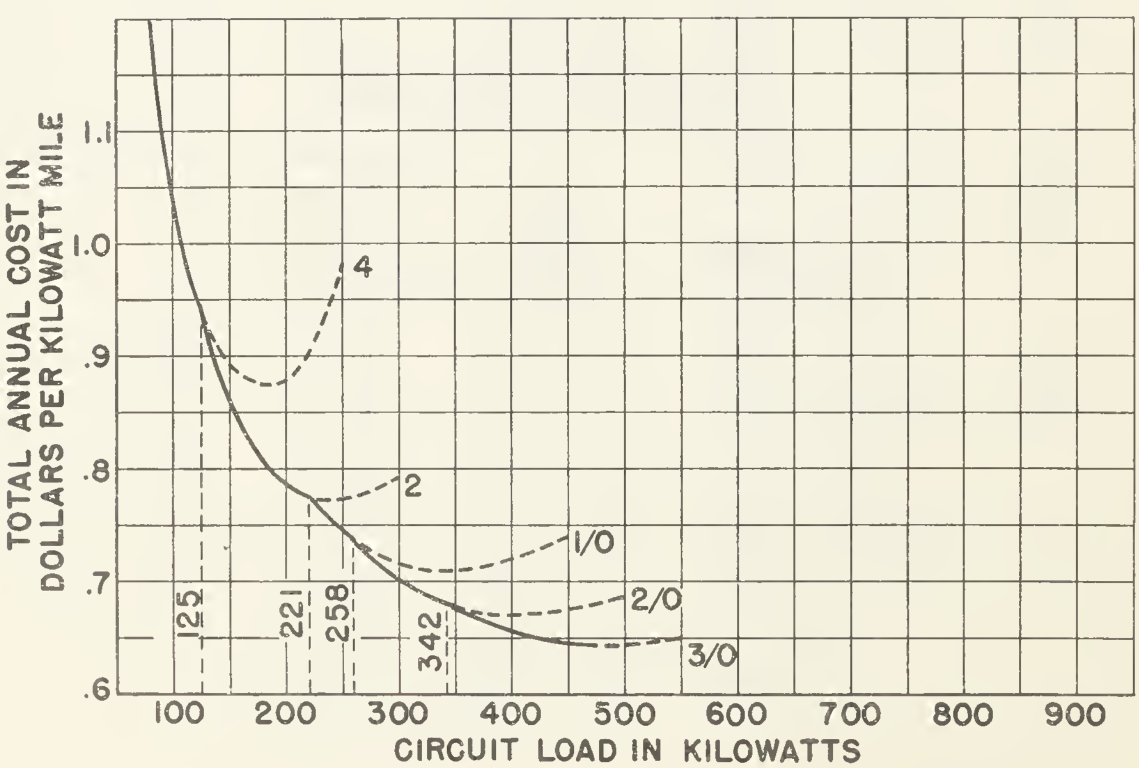

Fig. 3. Minimum Annual Cost of Single-Phase, Rural Distribution Lines, 7.2 KV, ACSR Conductor.

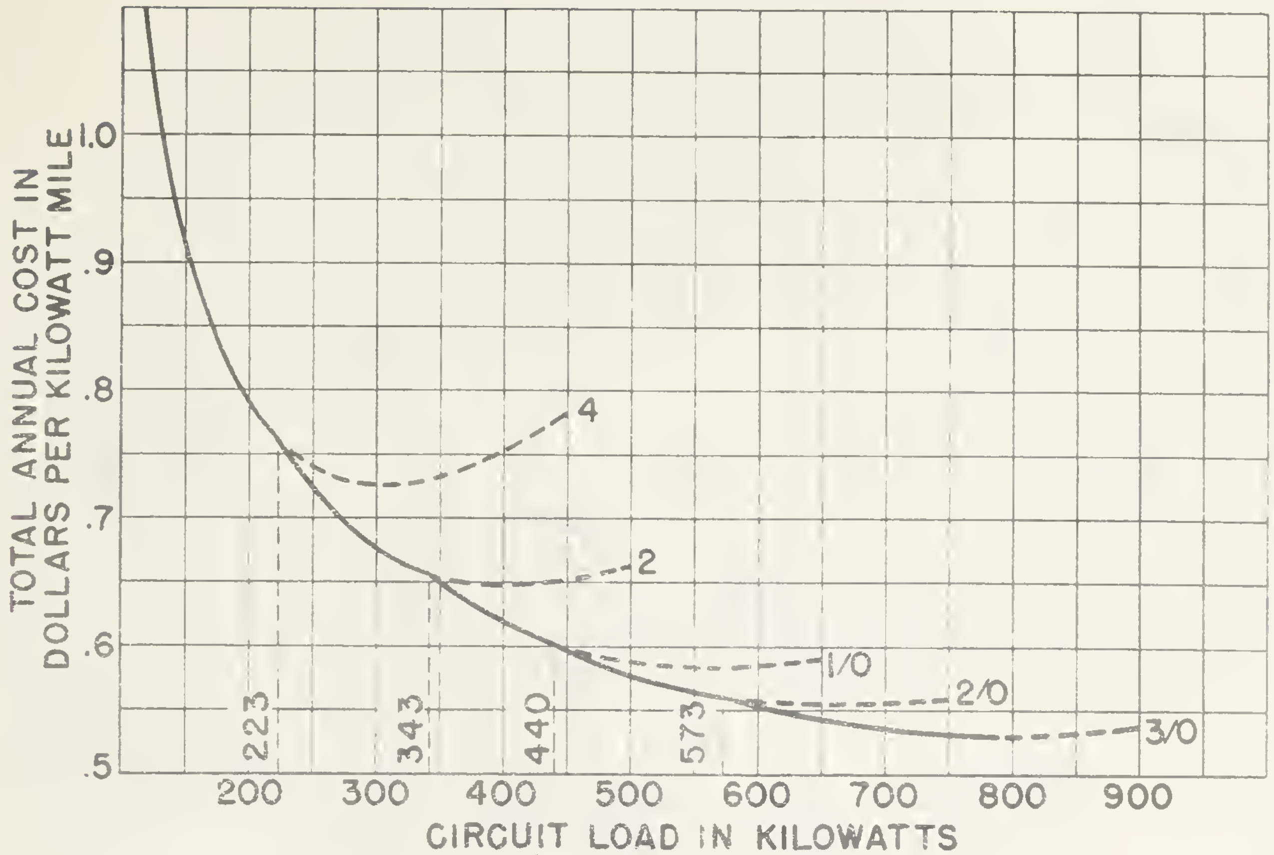

Fig. 4. Minimum Annual Cost of "V"-Phase, Rural Distribution Lines, 7.2/12.5 KV, ACSR Conductor.

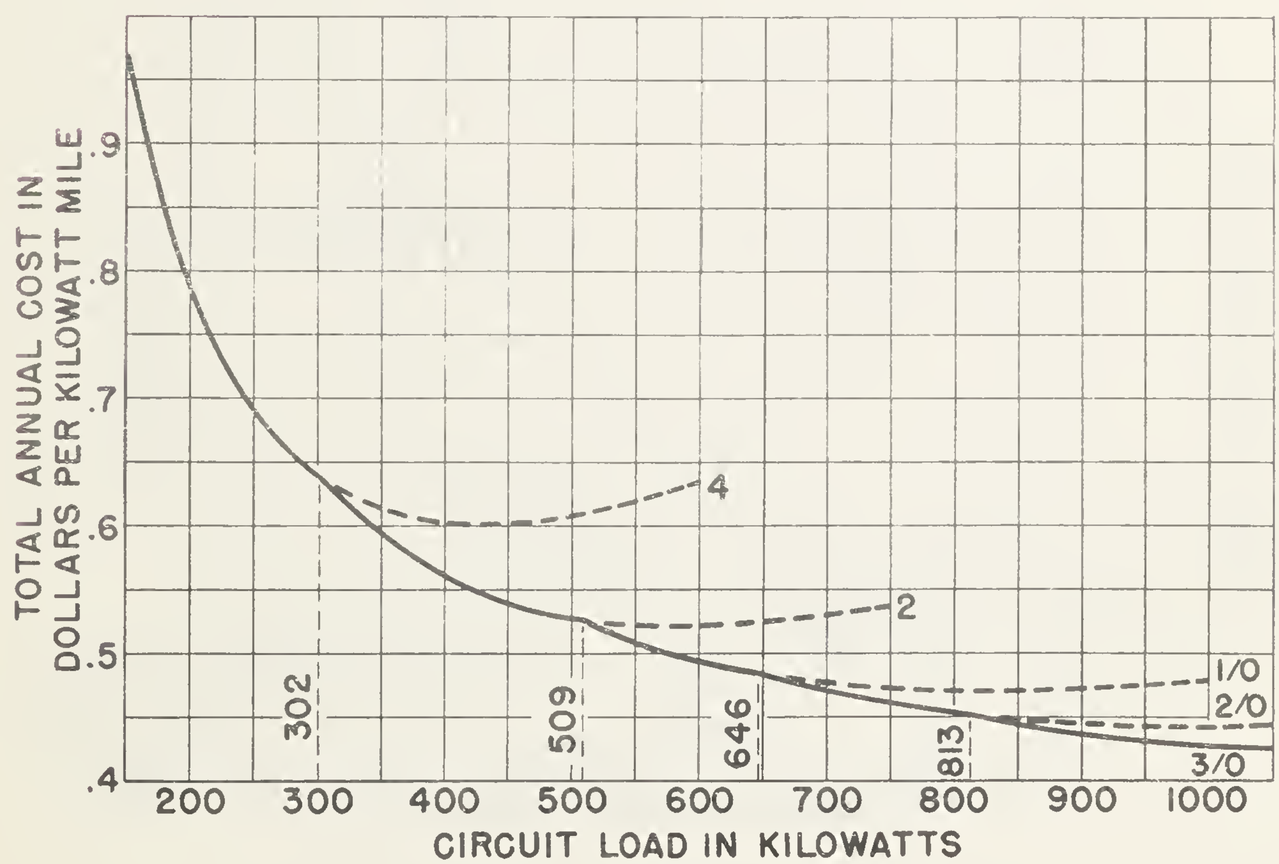

Fig. 5. Minimum Annual Cost of Three-Phase, Rural Distribution Lines, 7.2/12.5 KV, ACSR Conductor.

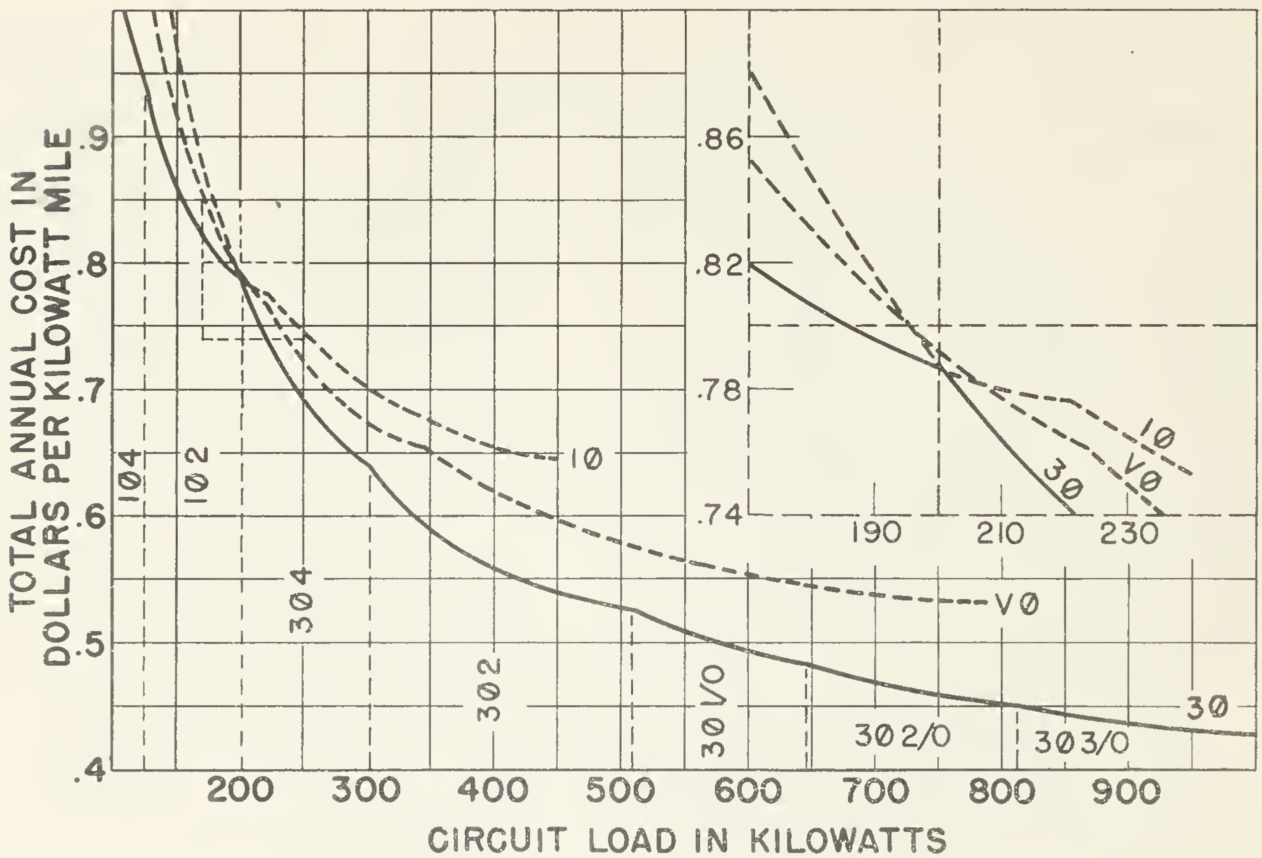

Fig. 6. Minimum Annual Cost of Rural Distribution Lines, 7.2/12.5 KV, ACSR Conductor.

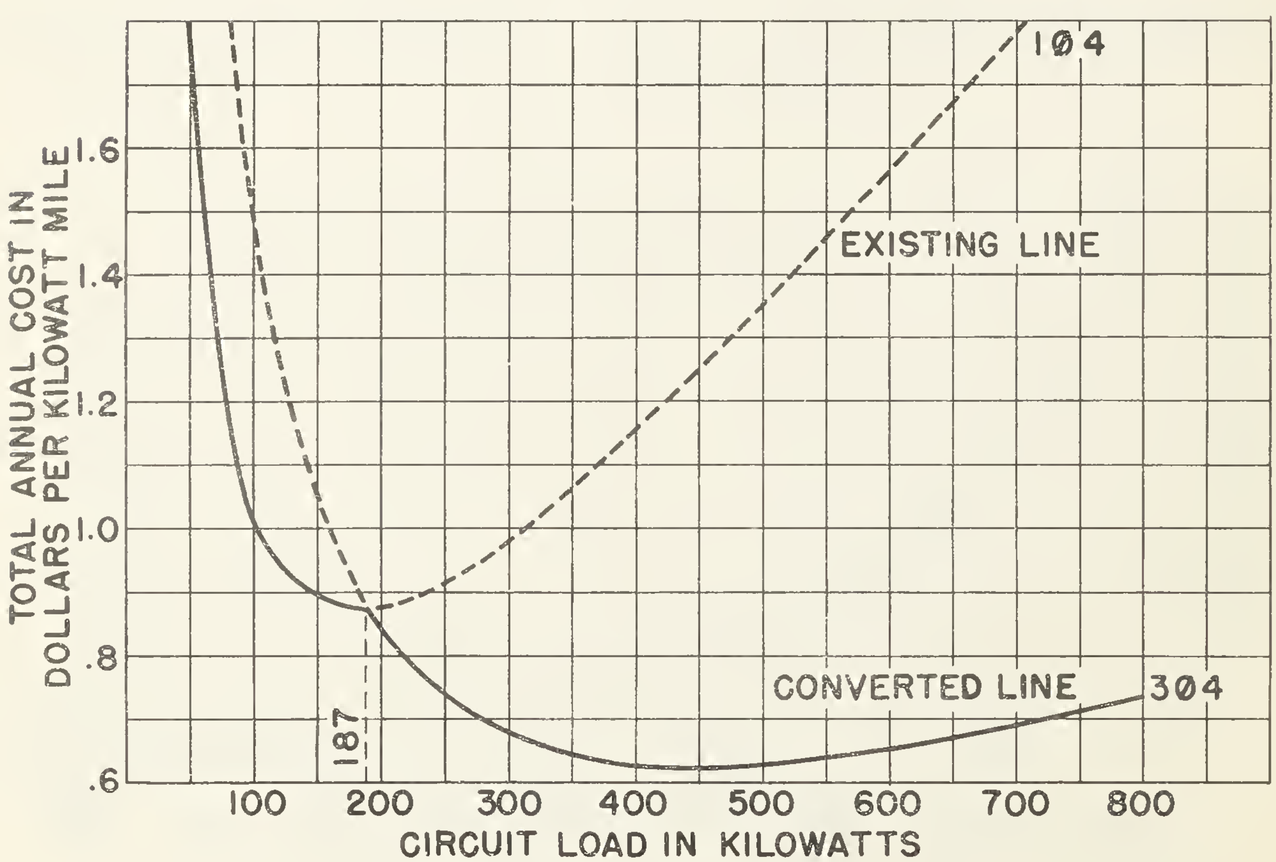

Fig. 7. Annual Cost of an Existing Single-Phase No. 4 ACSR and of a Converted Three-Phase No. 4 ACSR Rural Distribution Line, 7.2/12.5 KV.

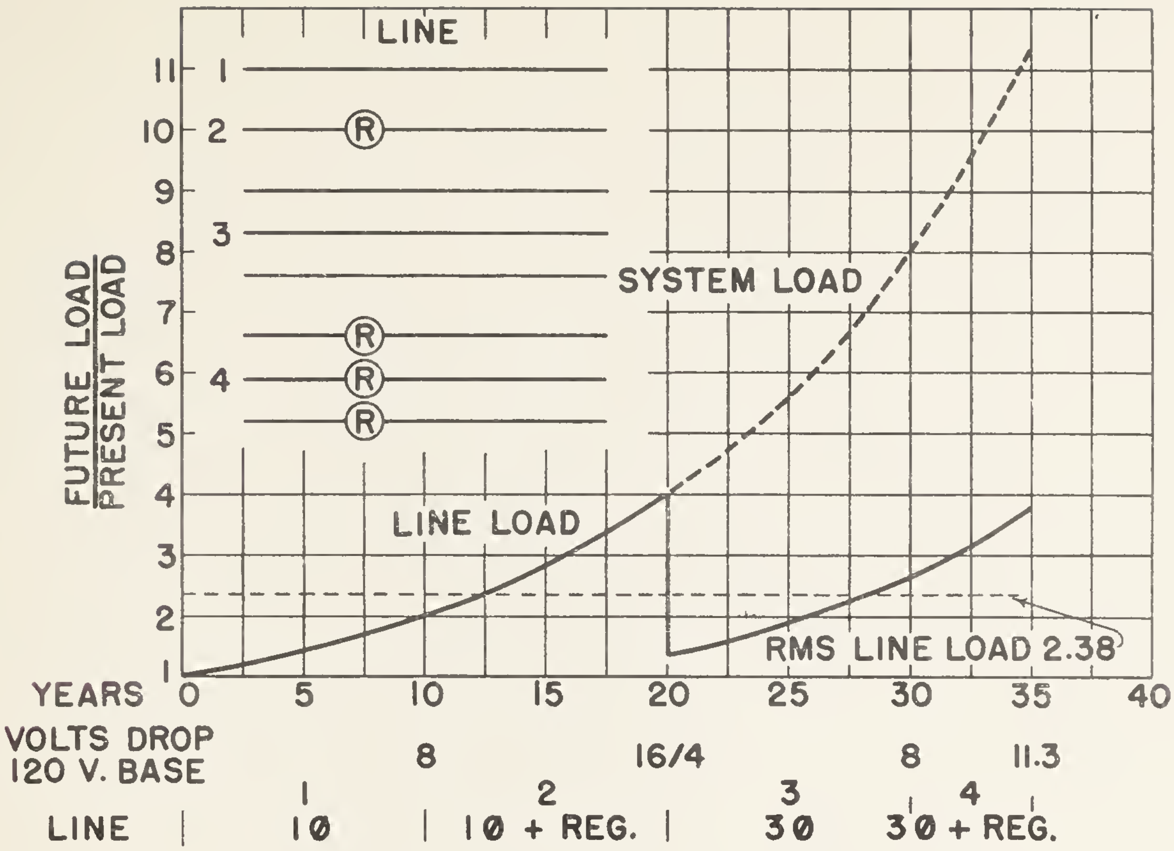

Fig. 8. Line Load Growth for a Single-Phase Distribution Line.

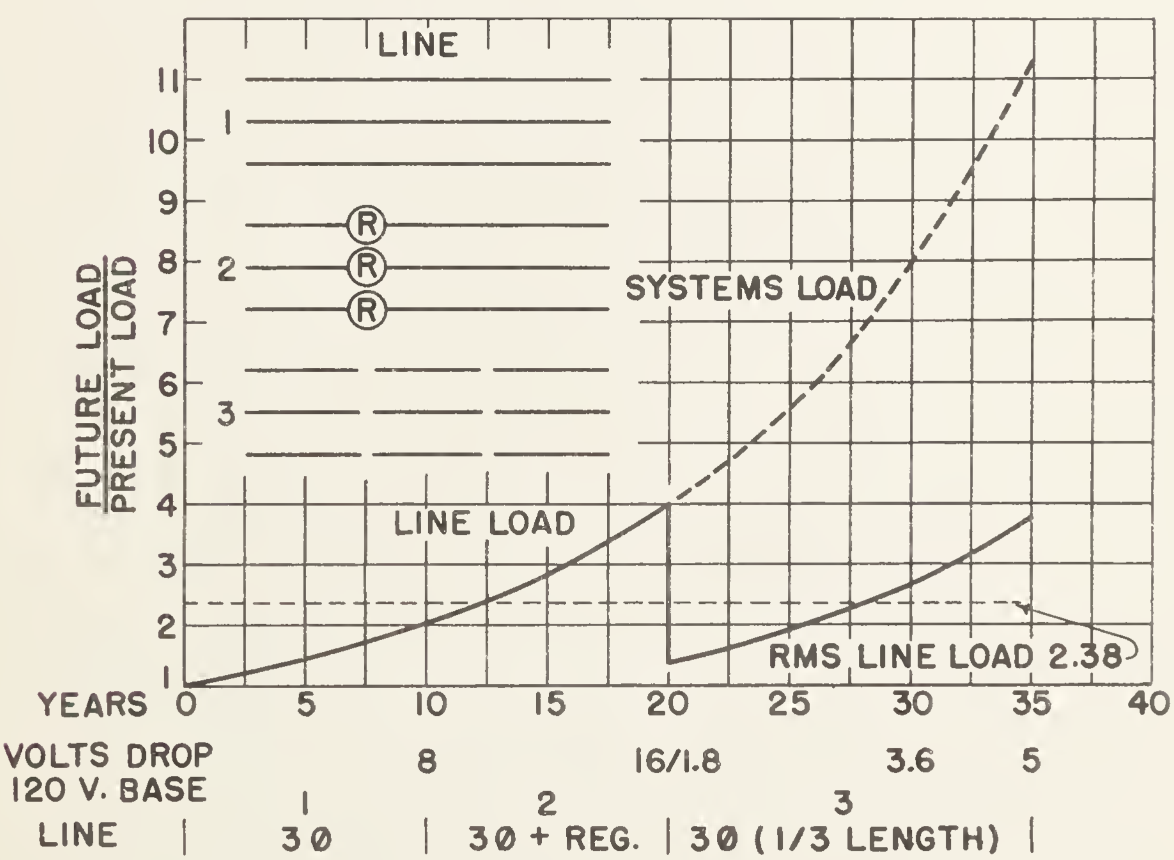

Fig. 9. Line Load Growth for a Three-Phase Distribution Line.

MAINTENANCE LIABILITY

By Clark A. Reid and Leean L. Huff
Field Engineers
Southwest Area

For Presentation at the 1956 Technical Conference
For REA Field Engineers, Saint Louis, Missouri
January 16 - 20, 1956

REA

U. S. DEPARTMENT OF AGRICULTURE

RURAL ELECTRIFICATION ADMINISTRATION

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To assure freedom for the development of ideas which may serve to improve the engineering of rural electric systems, the authors of papers and discussions have been encouraged to explore new ideas and new techniques and to prepare papers which reflect their own engineering judgment and experience. Such an approach may develop ideas which deviate from industry practices and REA policies and procedures presently in effect. It should be recognized, however, that REA policies and procedures as set forth in REA bulletins are still applicable unless changed in the light of the ideas and experience which may result from such papers or discussions.

R G Zook

R. G. Zook
Assistant Administrator

MAINTENANCE LIABILITY

Clark A. Reid Leean L. Huff

Proper maintenance of a utility system consists of keeping the plant in optimum condition. However, it is possible to neglect some maintenance without serious deterioration of service immediately. This is due to a utility being a high investment type of business with a slow turn-over of capital investment. A business which has a rapid turn-over of capital investment is affected very quickly by changes in maintenance activities. A utility may not show noticeable effects on its operations because of inadequate or decreased maintenance activities until a considerable period of time has elapsed. The cost of correcting accrued maintenance and restoring the system to optimum condition is frequently substantial. At some time this accrued maintenance will have to be performed and therefore constitutes an obligation which must be met. This is referred to as "maintenance liability". Competent management will determine the extent of such maintenance liability and will plan corrective action.

The value of the total maintenance liability is equal to that expenditure which will be required to correct all existing items of maintenance in order to bring the system up to original specifications, giving consideration to the effectsof age and normal wear. This condition is referred to as the "optimum condition" for the maintenance of a system.

The management of a business uses accounting records to reveal the condition of the business and to evaluate the progress being made. One such report is the "Balance Sheet" in which the accountant summarizes the assets and liabilities as shown on the records and derives the "Net Worth" of the business. Changes in the net worth over a period of time is a measure of the progress being made. However, accounting records do not include information on maintenance liability.

If management will prepare a tabulation in the form of a balance sheet in which the obligation for correcting the accrued maintenance is treated as a liability, then the actual status of the business will be revealed. Without this knowledge the true financial condition of the system cannot be known. The cash position may be offset partially or completely by the obligation of maintenance liability. What is considered to be a comfortable cash balance may prove to be woefully inadequate in case an unusually large maintenance liability exists. An improvement in the cash position may be due to non-performance of maintenance requirements. Conversely, a decrease in the cash on hand may be due to correcting maintenance liability. Neither of these conditions reflect any change in the actual net worth of the system but is merely an exchange of value between cash assets and other forms of assets.

The consideration of the cash position without considering the amount of the maintenance liability may lead to erroneous conclusions. The existence of an appreciable amount of maintenance liability can seriously affect the future operations and the security of the business. A board of directors which forms its opinion of the manager's operations by considering only the cash on hand forces the manager to place adequate maintenance in a secondary position. Lack of complete information regarding the amount of maintenance liability may cause REA to arrive at erroneous conclusions in regard to the security of a loan. Comparisons of the condition of different systems or of the same system at different times is impossible without including the amount of the maintenance liability in the consideration.

The term "maintenance liability" is used in a general sense and is intended to include all accrued obligations, regardless of the technical accounting treatment, such as accrued operations (right-of-way reclearing, etc.), maintenance, and replacements. It must be clearly understood that the estimates of the liabilities are not related to any accounting records but are an operating and planning tool only. Also the inclusion of items in the accrued operations, maintenance, or replacement obligations does not necessarily mean they should be corrected immediately. Management should economically plan and schedule the corrective work, giving preference to the most urgent.

DETERMINATION OF NET WORTH

The net worth of a business is represented by the excess of total assets over total liabilities. In order to prepare a tabulation of the assets and liabilities and determine the net worth which will reflect the maintenance liability, it is necessary to prepare a special tabulation of assets and liabilities which will include these operating factors. Since this information is not available from accounting records, Figure 1 is an example of such a tabulation.

All items included in the tabulation of assets are obtained from the current operating report with the exception of the reserves for deferred operations and deferred maintenance. These should be established in the amount of the corresponding liabilities as shown in this tabulation. The establishing of funds for replacements, deferred operations, and deferred maintenance in the tabulation of assets provides management with information regarding the adequacy of the cash and temporary investments in relation to the corresponding liabilities. For example, the operating report from which Figure 1 was prepared showed cash and temporary investments of $479,126.05 but, as shown in Figure 1, only $4,432.05 is available in excess of the operations, maintenance, and replacement liabilities. The original cost of the electric plant is included in the assets and no allowance is made for depreciation. This is due to the obligations for replacement and the debt to REA both being included in the tabulation of liabilities and reflects the actual practice of operating, maintaining, making replacements, and paying for the system during the term of the REA loan.

All items included in the tabulation of liabilities are obtained from the current operating report with the exception of the liabilities for replacements, accrued operations, and accrued maintenance. The liability for replacements is computed in accordance with the procedure outlined in REA Bulletin 103-2R1, "Use and Investment of General Funds", and the deferred operations and maintenance in accordance with the procedure of this paper.

The "net worth" will provide management with a good measurement of its activities. This is because it will not vary as does the operating margin or the cash balance as shown in the accounting reports. Extraordinary expenditures for increased operations or maintenance activities will not affect the net worth because the assets and liabilities will be reduced in the same amount. On the other hand, failure to perform current operations and maintenance will not increase the net worth because the accrued liability is increased in the same amount as the assets (which is cash accumulated due to not expending it in performing the work) is increased.

The "Statement of Net Worth" (Figure 1) should be prepared at regular periods of time, such as monthly, quarterly, or semi-annually, to reflect the changes in the assets and the liabilities. This would include changes in the funds and liabilities of the deferred operations and maintenance to show the work accomplished since the last statement as well as the additional accrual of obligations. At regular periods of time, such as annually or bi-annually, the maintenance liability should be re-determined. This can be done in a number of ways. Examples are; a new field inspection and appraisal of procedures can be made; the summary of routine patrols can be extrapolated to represent the whole system; summaries of actual work done on known lengths of line can be extrapolated to represent the whole system.

DETERMINATION OF MAINTENANCE LIABILITY

Although various types of time reports are used to furnish the information required for charging the labor and transportation costs to the proper accounts, information usually is not available as to the quantity of physical work accomplished. Therefore "Work Units" should be established for each type of activity. There are two types of work units; namely, "Maintenance Work Units", and "Operations Work Units". Tighten guys, plumb poles, and re-sag conductor are examples of maintenance work units. Re-clear right-of-way, patrolling, and moving transformer, are examples of operation work units.

The quantity of work accomplished, in number of work units, should be recorded on the time reports. It then will be very simple to summarize the time sheet data and establish costs for the various work units. This can be done by the use of a time sheet similar to Figure 2. The column headed "Number" is used to show the number of work units completed. Each month this information is tabulated and priced to get the average cost for each work unit. Construction and retirement work is accounted for by work orders. The work order procedure develops standard costs and retirement unit costs which furnish the information needed on replacements.

Appendix 1 shows a summary of the unit costs for work units prepared by a Missouri cooperative. This data was developed in the routine of regular activities. Unit costs for each month and the average unit cost for the period are shown.

It has been pointed out earlier that proper maintenance consists of keeping the facilities in optimum condition. This broad concept includes operating practices and replacements as well as maintenance activities, even though these three items are segregated for accounting purposes.

The amount of operations, maintenance and replacement work that needs to be done at any particular time can be determined by a field inspection of the physical plant and an appraisal of the operations and maintenance practices.

Usually it is not practical to make a pole-by-pole inspection of the entire system to obtain the amount of maintenance liability. Therefore, in most cases, it is necessary to make the field inspection on a representative sample of the system. The size and location of the sample should be determined by local conditions. The information regarding the condition of the plant as obtained from such an inspection should be recorded in such a manner that it may be summarized in work units.

The dollar amount of maintenance liability for accrued operations and accrued maintenance would then be determined by summarizing the work units for each classification, pricing the work units and totaling. In addition, the cost of installing needed operations and maintenance practices that are not now in use should be estimated for the period of time considered and included in the total.

The major item of accrued operations on many systems is right-of-way reclearing. The work unit of reclearing should be one span of pole line. A determination should be made as to the frequency of reclearing. For example, if it is determined that the right-of-way needs to be recleared every five years, the work units should be tabulated to show the number of units which should be recleared:

1. this year
2. in one year
3. in two years
4. in three years
5. in four years

The total liability for reclearing would be the sum of:

1. 100% x unit cost x number of units to be recleared this year
2. 80% x unit cost x number of units to be recleared in one year
3. 60% x unit cost x number of units to be recleared in two years
4. 40% x unit cost x number of units to be recleared in three years
5. 20% x unit cost x number of units to be recleared in four years.

Examples of operations practices that should be estimated and included in the cost are voltage surveys, routine patrols, substation inspections, etc.

The major items of accrued maintenance will be determined by the field inspection. Meter maintenance is usually scheduled on a recurring cycle and the liability would be computed in the same manner as shown for right-of-way reclearing. Liability for recloser maintenance is an example of the type of maintenance which would be determined from the appraisal of activities and not by field inspection.

The liability for replacements is determined in accordance with the procedure outlined in REA Bulletin 103-2R1. Replacements that need to be made currently will be revealed by the field inspection.

CONCLUSIONS

The maintenance work that exists at any time constitutes a liability. Maximum benefits can be derived from a knowledge of the maintenance liability only when both the amount of work involved and its financial effect on the system are known. Proper correlation of this information is necessary for economical and efficient planning.

The work units and their costs will be extremely valuable to management for other purposes in addition to determining maintenance liability. They will be useful in the budgeting and planning of the work. Comparisons of the costs will serve as a measure of efficiency.

STATEMENT OF NET WORTH, SHOWING EFFECT OF MAINTENANCE LIABILITY

As of January 1, 1955

Assets

Amount	Item	Line No. in Operat. Report
$5,202,749.52	Total Elec. Plant	(5)
19,917.45	Materials and Supplies	(16)
13,876.29	Accounts & Notes Receivable	(14, 15)
	Other Physical Property	(8)
18,390.91	Current Assets & Deferred Debits	(17, 19)
82,059.06	REA Loan Funds	(11)
303,194.00	Fund for Replacements	(10)
136,000.00	Fund for Deferred Operation	*
35,500.00	Fund for Deferred Maintenance	*
4,432.05	Cash & Investments	(9, 12, 13)
$5,816,119.28	TOTAL ASSETS	

Liabilities

Amount	Item	Line No. in Operat. Report
$4,613,412.43	Debt to REA	(21)
	Other Debt	(22)
106,392.34	Membership Fees & Contributions	(32, 38)
17,904.30	Contributions in Aid of Construction	(31)
	Accts Payable, Construction	(24)
	Accts Payable, General	(23)
5,890.00	Consumers Deposits	(27)
	Patronage Refunds & Credits	(25, 33)
	Matured Debt	(26)
29,795.35	Current Liabilities & Deferred Credits	(28, 30)
303,194.00	Liability for Replacements	**
136,000.00	Liability for Accrued Operations	***
35,500.00	Liability for Accrued Maintenance	***
$5,248,288.42	TOTAL LIABILITIES	
567,830.86	NET WORTH	
$5,816,119.28	TOTAL	

* Established in the amount of the Deferred Liability

** REA Bulletin 103-2

***To be estimated in accordance with recommendations of this paper.

Figure 1. Statement of Net Worth, Showing Effect of Maintenance Liability

TIME SHEET

ENDING: ______ BEGINNING: ______ TOTAL: ______	CREW				DATE: ______ TRUCK NO. ______

Description of Work	Acct. No.	Hours Worked				Number	Miles
Cutting Trees	761						
Trimming Trees	761						
Stump Spraying	761						
Basal Treatment	761						
Voltage Check - Line	761						
Testing & Boring of Poles	761						
Disc. for House Moves, etc.	761						
Patroling Line	761						
Change Transformers	761						
Change Breaker or Sectionalizer	761						
T. V. Interference	762						
Radio Interference	762						
Customer Contact	762						
Yard Light Bulb Replacement	762						
Voltage Check - Consumer	762						
Connects	762						
Disconnects	762						
Meter Changes for Test Fee	762						
Pole Alignment	768						
Tightening Hardware	768						
Backfill Anchors	768						
Backfill Poles	768						
Set Poles Down	768						
Tighten Guys	768						
Resag Conductors	768						
Install Minor Items	768						
Repair Ground	768						
Change Out Insulator	768						
Reset Ground Rods	768						
Sleeve Wire	768						
Move Ground Wire from Hardware	768						
Outage - Power Supplier	768						
Outage - Line	768						
Outage - Individual	768						
Road Moves	768						
Collecting	780						
Reading Meters	780						
Safety Meeting	800						
Work Orders - Construction							
Work Orders - Retirement							
Total Hours							

Figure 2. Time Sheet

APPENDIX 1.

TABULATION OF QUANTITIES AND COSTS FOR WORK UNITS

	July 1954		October 1954		November 1954		December 1954		January 1955		February 1955		March 1955		April 1955		May 1955		Entire Period	
	No.	Unit Cost	No.	Unit Cost	No.	Unit Cost	No.	Unit Cost	No.	Unit Cost	No.	Unit Cost	No.	Unit Cost	No.	Unit Cost	No.	Unit Cost	No.	Unit Cost
Align Pole	5	1.00	10	1.07	24	.96	55	.82	17	1.34	2	1.68	11	1.51	26	1.32	6	1.18	156	1.09
Tighten Hardware	18	.65	33	.55	126	.54	178	.68	90	.71	39	.70	67	.64	135	.53	16	.76	702	.62
Trim Tree	11	1.82	8	1.67	52	2.55	131	1.90	10	3.12	25	2.93	89	2.14	70	2.00	12	2.69	408	2.16
Backfill Pole	4	.42	19	.21	31	.17	76	.62	39	.55	36	.46	70	.50	63	.48	8	.42	346	.48
Tighten Guy	7	.46	25	.39	49	.59	79	.68	21	.93	39	.68	56	.76	53	1.10	10	.85	339	.74
Backfill Anchor	2	.84	7	.35	6	.68	36	.46	4	.83	20	.91	17	.88	19	.80	7	.50	118	.68
Cant Pole	5	.34			5	.66	32	.32											42	.52
Test Pole			10	.40	9	.73	26	.84	2	1.64	5	.66	18	.55	4	1.25	6	.59	80	.72
Reset Anchor			1	1.63															1	1.63
Bond Neutral					1	1.63													1	1.63
Replace Insulator					5	1.84	3	2.79	3	1.68	3	2.73	2	1.66	2	5.25	2	1.84	20	2.41
Repair Ground					1	.56	27	.42	4	.83	3	1.10	2	1.66	6	1.14	1	1.71	44	.69
Resag Service					4	.93	9	.73			6	2.23							19	1.25
Resag Primary					1	.42	4	2.51	11	1.80			9	1.63	13	1.58	1	1.76	39	1.73
Sleeve Conductor					2	2.27	1	1.63	1	4.92									4	2.77
Cut Pole Top Off							5	1.29			1	3.36	2	3.36					8	2.07
Replace Nuts and Washers							4	.40											4	.40
Unwrap Service							2	.87											2	.87
Replace Connectors							3	.54											3	.54
Install Minor Items			15	.06	19	.52	76	.41	37	.54	33	.40	43	.43	28	.87	4	.90	255	.46
Move Ground From Hardware									14	.59	16	.92	14	.60	2	.85			46	.72
Reset Pole									4	.80					2	2.63			6	1.41
Voltage Check - Consumer											7	1.19	7	.72	11	.65			25	.82
Replace Yard Light											1	1.68							1	1.68
Cut Tree											4	3.36	12	2.73	25	1.02	1	3.59	42	1.80
Radio Interference													1	3.36	2	3.50			3	3.44
Consumer Contact													48	.71	31	.77	8	.88	87	.75
TV Interference													1	3.28	1	3.42			2	3.35
Outage - Individual													1	3.28					1	3.28
Reset Ground Rod													2	1.66			2	1.84	4	1.75

STEP TYPE REGULATORS

By Robert E. Horn, Sales Engineer
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For Presentation at the 1956 Technical Conference for
REA Field Engineers, Saint Louis, Missouri
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R. G. Zook
Assistant Administrator

STEP TYPE REGULATORS

R. E. Horn

This paper describes the basic makeup of a step type regulator, its uses and capabilities.

The step type regulator was originated in 1933 to provide an economical means to regulate high voltage lines. Load growths and new construction meant greater uses of higher voltages and high voltage regulating equipment. A regulator was needed that was economical to operate and was trouble free in operation. It was known for sometime that an autotransformer met the requirement for higher voltages and due to its lower exciting current and many other inherent advantages it has become the leading regulating device for all distribution voltages.

AUTO-TRANSFORMER

Auto-transformer design is covered in texts readily available therefore it is necessary to discuss only the simple connection diagram shown in figure 1.

Auto-transformers raise or lower the voltage depending upon the polarity of the secondary or series winding as shown in figure 1a for raise and 1b for lower. Standard step type regulators raise or lower the voltage ten percent by an automatic reversing switch shown in figure 1c. There are also non-standard step regulators which have from plus and minus five percent regulation to plus and minus fifteen percent regulation. Some have regulation in only one direction. The difference is in the design of the series winding.

Standard regulators have the series winding tapped in eight equal increments giving 1 1/4 percent taps as shown in figure 2. These taps are connected to stationary contacts on a tap changing mechanism.

PREVENTIVE AUTO-TRANSFORMER

The 1 1/4 percent taps result in 5/8 percent steps by introducing a preventive auto-transformer into the circuit. The preventive auto-transformer has leads brought out from each end of the winding and is center tapped. The center tap is connected to the load bushing.

The leads brought out from the ends of the preventive auto-transformer are connected to moving contacts. The moving contacts are mechanically spaced so both contacts can be either on one stationary contact or on adjacent contacts. The latter is a bridging position.

When the movable fingers are in a bridging position the center tap of the preventive auto-transformer effectively gives another tap on the series winding. This effective tap is one half of the 1 1/4 percent main tap giving 5/8 percent steps.

With the moving contacts in a bridging position circulating current is set up in the closed loop. This is due to the difference in voltage of the taps. Sufficient impedance is built into the preventive auto-transformer to limit the

circulating current. Even when load current is zero, the preventive auto-transformer has current flowing through it in every bridging position.

When the movable contacts are on the same stationary contact and the regulator is carrying load, the load current divides equally between the two moving contacts.

The instant one contact leaves a stationary contact the opposite leg of the preventive auto-transformer carries full load current giving continuity of service while changing taps under load.

TAP CHANGING MECHANISM

The tap changing mechanism controls the movement of the moving contacts from one stationary contact to the next. One essential requirement is high speed contact separation to minimize contact deterioration. Simplicity of design is also required to allow for ruggedness of individual parts. Auto-transformer life is quite long under normal operating conditions therefore everything is done to match this life in constructing the mechanical parts of the tap changer.

CONTROLS

The automatic controls (figure 3) consist of seven basic components. These are (1) Potential transformers, (2) Current transformers, (3) Voltage level rheostat, (4) Voltage regulating relay, (5) Reactance compensator, (6) Resistance compensator, (7) Time delay or Voltage Integrator.

The potential transformer is located on the regulated side of the regulator to give regulated voltage to the automatic control and desired recording instruments.

The voltage level rheostat varies the voltage in the voltage regulating relay solenoid. This allows setting the voltage level that the regulator will maintain from 105 to 130 volts.

The voltage regulating relay consists of a solenoid with a soft iron plunger, an arm connecting the plunger to a bearing and a set of contacts connected to the arm. The plunger varies its position in the solenoid depending on the voltage in the coil. High voltage moves the plunger upward and low voltage downward. Fluctuations in source voltage reflect in the potential transformer and causes the plunger to rise or fall depending upon the voltage effect on the solenoid.

The electrical distance between the two stationary contacts of the regulating relay is called the voltage bandwidth. The bandwidth is the working tolerance of the regulator and is usually 2 volts. If the voltage level were set for 120 volts the voltage could vary between 121 and 119 volts without the tap changer operating. The voltage bandwidth can be set for greater or lesser widths if desired. If the voltage exceeded these limits the regulator operates to bring the voltage back into the bandwidth.

The beam of the voltage regulating relay is spring suspended for friction free movement. It is sensitive to change of voltage but dampened to mechanical vibrations.

The intelligence of the voltage regulating relay is not immediately given to the automatic tap changer but first passes through the time delay or Voltage Integrator. This eliminates hunting and unnecessary tap changes. The integrating portion of the time delay allows the regulator to watch voltage variations over a period of time. If these variations are outside of the bandwidth for a total time longer than they are inside the bandwidth, the integrator trips a switch which operates the tap changing motor. The tap changer then raises or lowers the voltage to bring it back into the preset bandwidth. The time delay on the integrator can be varied.

The resistance rheostat, reactance element, and current transformer make up the line drop compensator circuit. Where the voltage regulating relay corrects the source voltage, the "line drop compensator" corrects for voltage drop due to load from the regulator to a particular point on the system called load center. This allows the regulator to be located at one point but give controlled voltage at another point, within the limits of the regulator.

INSTALLATION

Physical installations vary with operating practices throughout the country. Pole mounting (figure 4) of small single phase regulators is most economical and allows versatility as to location. As units grow in size a point is reached where some form of substation installation is more acceptable (figure 5).

A regulator must be on the neutral or 0 position before connecting or removing from a hot line. The control switch must be in the off position to insure that the regulator does not make a tap change while the switching is being carried out. To insure positive de-energizing of the control, the fuses or breakers on the control panel should be opened.

A definite procedure should be set up for installing regulators and the following should become second nature to everyone.

1. Regulator must be on neutral
2. Control switch must be on off position
3. Fuses must be out
4. Close source side switch
5. Close load side switch
6. Open by-pass switch

When removing a step type regulator from service, the following steps are required.

1. Regulator must be on neutral
2. Control switch must be on off position
3. Fuses must be out

4. Close by-pass switch

5. Open load side switch

6. Open source side switch

By-passing a step type regulator off neutral sets up circulating currents which can destroy the series winding of the regulator and vaporize the cables from the bushings of the regulator to the by-pass switches if they do not have sufficient cross section. When by-passed off neutral, as much as 320 times rated current may flow if the regulator is one step off neutral (figure 6).

Setting the automatic controls is relatively easy on modern controls. The bandwidth is preset at the factory for 2 volts, the voltage level rheostat is calibrated from 105 to 130 volts for ease in setting the voltage level. The only check required is to determine the accuracy of the two calibrations after energizing the regulator.

Compensation settings are calculated for each individual installation using care not to exceed the voltage limitations of the first customer.

Information needed to calculate compensation settings are: Type of conductor (copper or aluminum), size of conductor and spacing, configuration of lines, current transformer rating, potential transformer rating, type of installation (open delta, closed delta, single phase, wye connection) and transmission line resistance and reactance table.

Instruction manuals accompanying regulators outline the steps for calculating compensator settings, therefore will not go into it here.

OVERLOADING

Overloading often becomes a necessity through system equipment failures, sudden load growths or planned outages. Knowing how far to overload during emergency conditions as well as planned conditions will realize longer life and a greater degree of continuity of service.

A great advantage of step regulators is their low losses. The maximum losses of a step regulator are only realized when the tap changer is at the maximum position. As the tap changer moves closer to its neutral position, lower losses result. This change of losses with position can be capitalized by increasing the load on the regulator as it moves closer to neutral (figure 7). This allows greater loading of step regulators without exceeding standard ASA temperature rise.

Curve A, figure 7, gives values for single phase, single core regulators designed so 200 percent of rated current may be carried on the 5 percent taps. This regulator can carry 133 percent nameplate current at 10 percent regulation without exceeding ASA temperature rises.

Curve B, figure 7, is for single phase, single core regulators designed so 160 percent of rated current may be carried on the 5 percent tap and intermediate overcurrents on intermediate taps.

Curve C, figure 7, gives values for three phase, single core regulators designed for 126 percent rated current at 5 percent tap and intermediate overcurrents on intermediate tap.

Curves D and E, figure 7, are for three phase regulators of two core, four winding and three winding respectively. For these two designs there is a much smaller change of losses over the full range of regulation, therefore less change in allowable overcurrents. This is due to the constant loss of the series transformer.

MAINTENANCE

Preventive maintenance is an age old question. For those fortunate enough to have a preventive maintenance program a suggested cycle for examination of step regulators would be after one year of operation and every five or six years thereafter. Loads and operating conditions will vary this suggested inspection cycle.

Examination of all step regulators would be in order after the first year of operation by everyone. This catches shipping damages that weren't visible at time of installation and unusual operating conditions.

Oil samples should be run with the same frequency as large transformers using the first oil test as the base for comparing subsequent tests. Here again loading and operating conditions influence frequency of oil inspections.

The controls of the regulators should be checked periodically to insure that the regulator is operating correctly for change of loading conditions.

Maintenance of regulators can best be decided by using common sense based on loading of the equipment and atmospheric conditions.

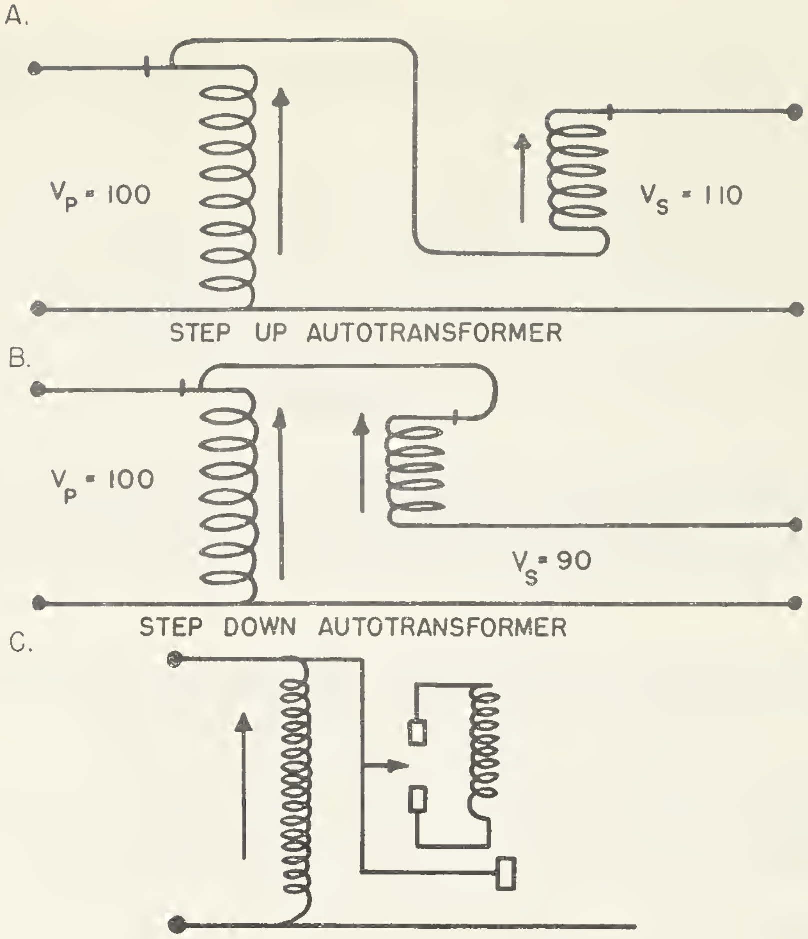

Fig. 1. Auto-transformer connection diagrams

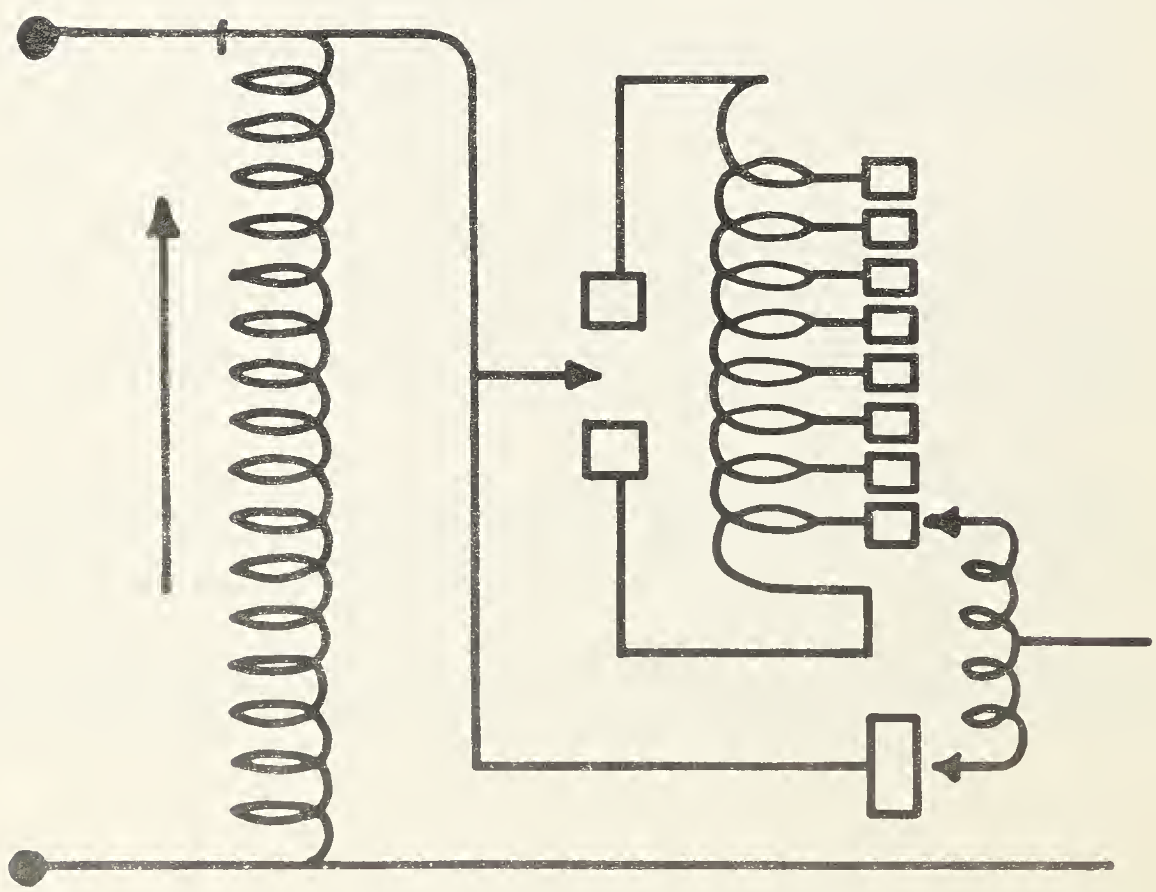

Fig. 2. Schematic diagram of single-phase step-type voltage regulator

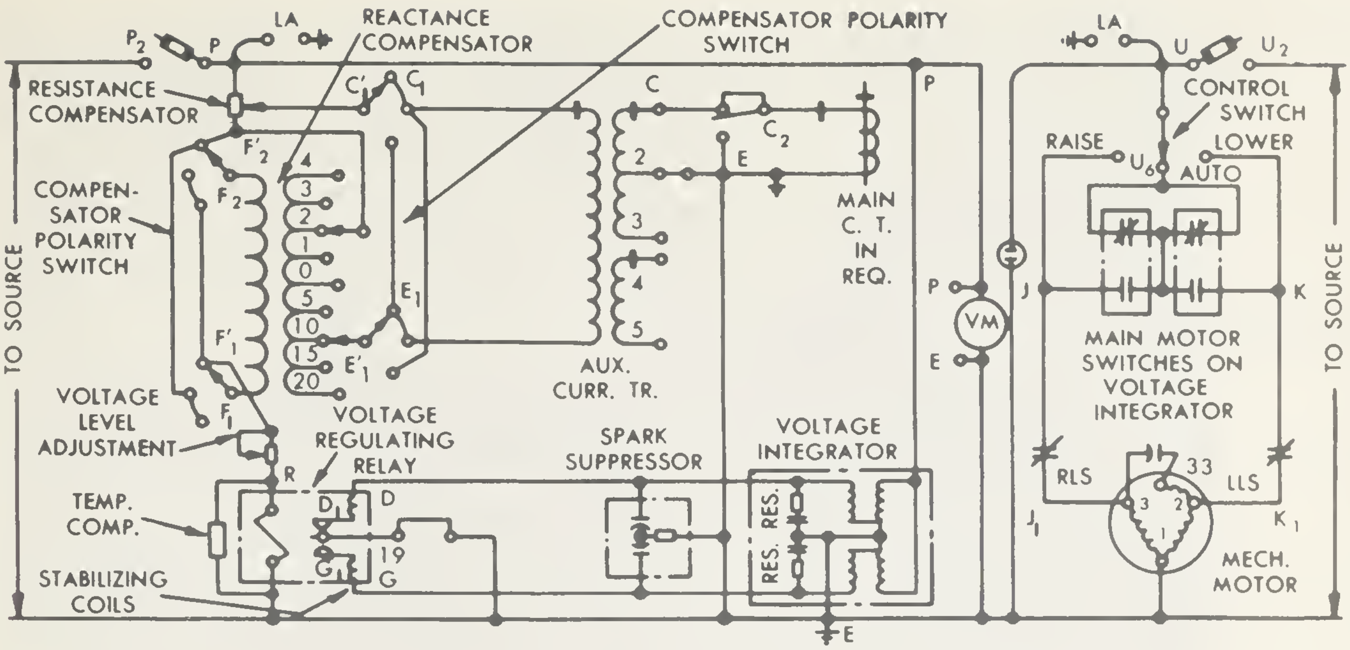

Fig. 3. Schematic diagram of feeder voltage regulator control

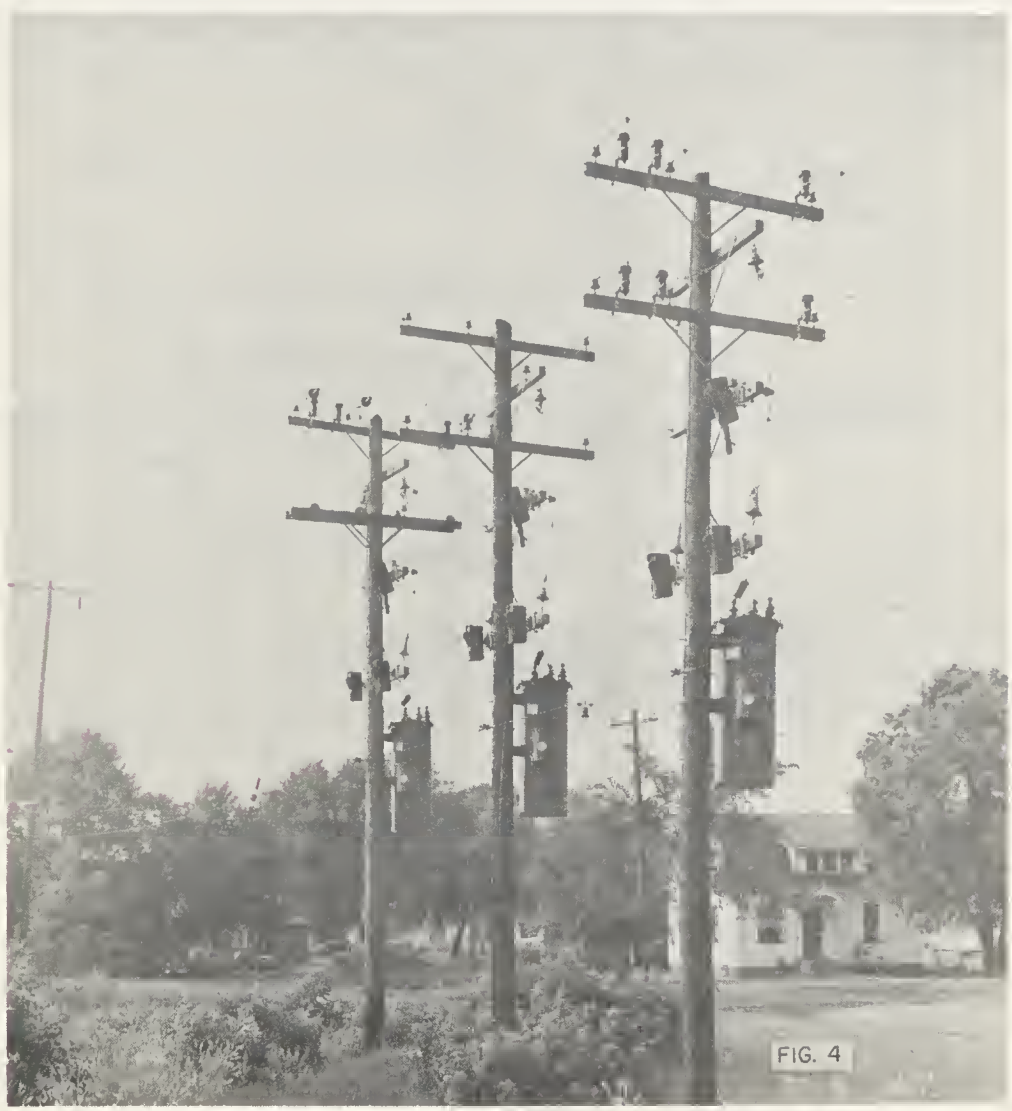

FIG. 4

Fig. 4. Pole mounted single-phase regulators

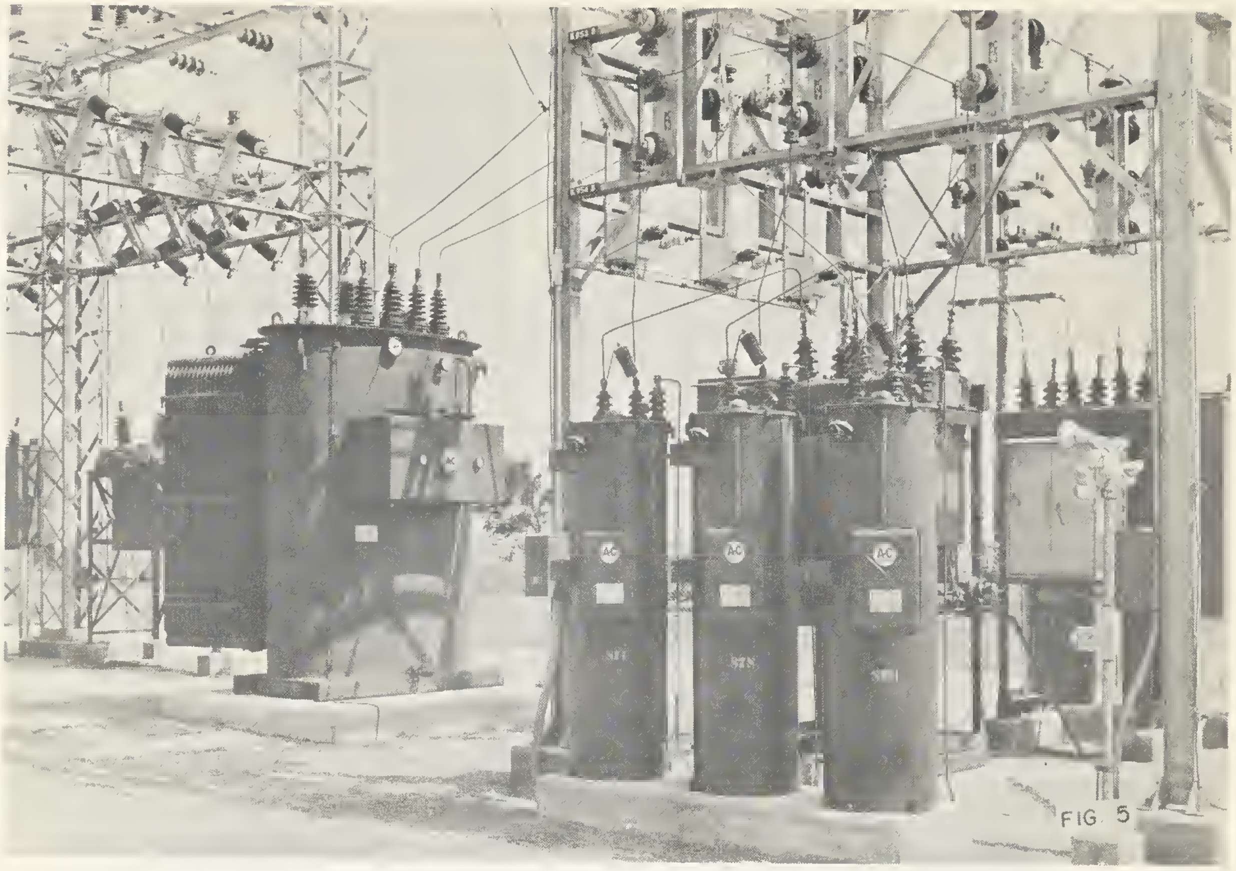

Fig. 5. Substation installation of single-phase regulators

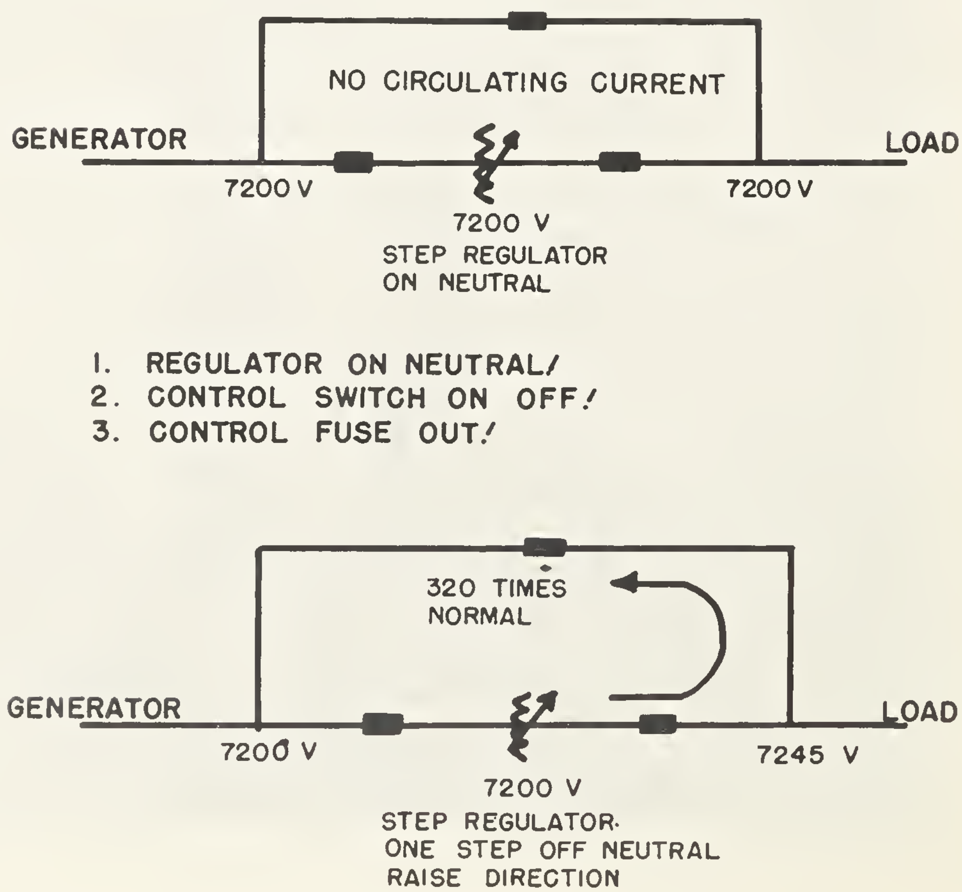

Fig. 6. By-passing step-type regulators

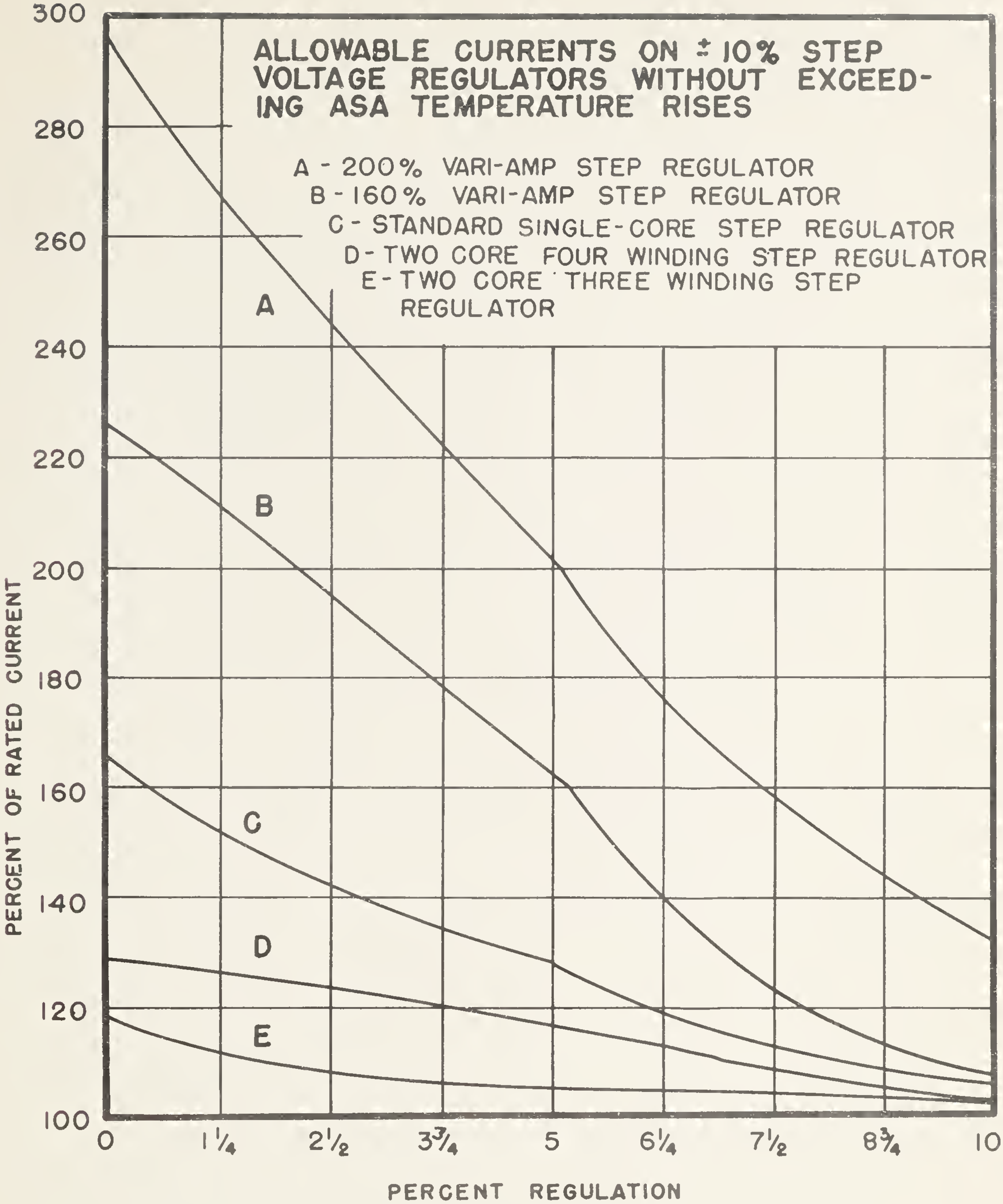

Fig. 7. Regulator overload curves

DISTRIBUTION VOLTAGE
A COMPARISON OF 12 KV AND 4 KV SYSTEMS

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Both of: Union Electric Company of Missouri

For Presentation at the 1956 Technical Conference for
REA Field Engineers, Saint Louis, Missouri
January 16 - 20, 1956

U. S. DEPARTMENT OF AGRICULTURE

RURAL ELECTRIFICATION ADMINISTRATION

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To assure freedom for the development of ideas which may serve to improve the engineering of rural electric systems, the authors of papers and discussions have been encouraged to explore new ideas and new techniques and to prepare papers which reflect their own engineering judgment and experience. Such an approach may develop ideas which deviate from industry practices and REA policies and procedures presently in effect. It should be recognized, however, that REA policies and procedures as set forth in REA bulletins are still applicable unless changed in the light of the ideas and experience which may result from such papers or discussions.

R G Zook

R. G. Zook
Assistant Administrator

DISTRIBUTION VOLTAGE
A COMPARISON OF
12 KV AND 4 KV SYSTEMS

S. F. Joyce   V. A. Gehrer

Introduction

An eminent psychologist recently published a list of suggestions for presenting ideas in a form which convinces, by proper use of the principles of persuasion. "Unfortunately, in this imperfect world, it is often the soundness of the presentation, regardless of the ideas, which convinces others", he said. On the other hand, a prominent management consultant wonders if we have come to the point where a good many of us spend more time dreaming up neon lights and hula girls for the presentation than we spend on thinking through the problem itself and a recommendation. There appears to be some disagreement between the experts. Yet if these two men were brought together for a discussion, the area for disagreement might prove not as great as it appears. Each would have to admit, if they were reasonable men, that the other's ideas had some merit and the differences were a matter of degree.

The general subject of 4 kv or 12 kv distribution systems seems to fall in this category. The technical literature for some time has contained many articles dealing with comparisons of 4 kv and 12 kv distribution systems. Some articles have described how a company adopted the 12 kv distribution voltage or is engaged in a program of changing to the higher voltage. There is still not complete agreement, though. There are people who believe that all of the benefits of the higher distribution voltage may be obtained at once and therefore the higher voltage should be universally applied. Some believe the cost of the 12 kv system is prohibitive and there are others who can see merit in both arguments and are willing to apply both systems as conditions warrant. Our company has made limited use of 12 kv, for the most part in outlying or low density areas. We have for some time felt the need of reviewing for our own benefit the advantages and disadvantages of 4 kv and 12 kv distribution systems. We hope that such a comparison will be of interest to this group.

General Considerations

There are some general criteria concerning comparisons of distribution systems which should be reviewed. It is generally agreed that in order to compare distribution systems on a cost basis or any basis, it is necessary that simultaneous consideration be made of the following items:

1. Distribution substation
2. Subtransmission system
3. Primary system
4. Secondary system

Detailed examination of one of these items without proper respect for the others, may result in a higher cost distribution system or unsatisfactory performance. Factors that are considered in the detailed analysis are voltage regulation, losses, conductor size, standards of service, operation and maintenance, load density, ability to expand, and overall cost.

Reasons For Higher Voltages

Our distribution system represents about 1/3 of the total system investment. Most of the distribution is 4 kv and has given good service except in isolated cases. It is only reasonable that we should take more than a passing interest in any plan that may result in changing or replacing the existing system.

The first question we would naturally ask is what are the reasons for considering a higher distribution voltage such as 12 kv? What benefits can be derived from a higher voltage? In general, high voltage can be expected to carry greater loads or cover greater distances. It may be required to do both for the load is growing over a greater area. We may require that the higher voltage produce a savings over existing facilities or we may accept it at higher cost because the lower voltage cannot do a specific job in a given area. One area may be experiencing poor voltage and consideration could be given to correcting the situation by changing voltage levels entirely. Load densities might be so low as to make loading of a 4 kv feeder very difficult. Flicker from motor loads may be a pressing problem in some areas and the higher voltage would permit accepting larger single phase motor load.

Many Factors Govern Voltage Choice

It soon becomes apparent, though, that the whole story is not merely a comparison of 4 kv and 12 kv. Characteristically, varying one part of a distribution system may have far reaching effects and so we now find ourselves concerned with the subtransmission and supply. It is recognized that many of the advantages of the 12 kv distribution system are interrelated and depend on the design of the specific systems. It is difficult to obtain all of these advantages at once because of the many factors of judgement and design that govern the choice of a 4 kv or 12 kv system. The chief factors, as far as we are concerned, will be mentioned here. In any comparison of 4 kv and 12 kv system a similar degree of service should be provided. This concerns both voltage and continuity and may be difficult to rationalize. Continuity involves a decision as to how much load or how many customers can be interrupted by a feeder failure. From an operating viewpoint, we have actually limited loading of 12 kv feeders so that an interruption would not affect too large an area. When the load density increases in the 12 kv areas, we believe we will limit feeder loads to the maximum of about 3,000 kva, which we have found the practical limit for 4 kv. Whatever choice of voltage is made should be an economical choice over a long range. The economical choice will be affected greatly by the existing system. All utilities have special problems concerning the existing system and its relation to the future system. Such items as voltage regulation, number of voltage levels, maintenance, operation, city or county laws and flicker problems all will have some bearing on the choice of voltages.

Studies Elicit Varied Conclusions

It has been stated that the technical literature for some time has contained many articles dealing with comparisons of 4 kv and 12 kv distribution systems. Some of these comparisons have been rather complete, dealing with everything from the economics of theoretical systems to practical aspects such as tree trimming. In fact, much prior work and study has been devoted to the subject, but different opinions still exist. Some engineers conclude from their studies that higher voltage in the distribution system, from customer to substation, is unquestionably the answer. They point to statistics that show the use of higher distribution voltages is increasing and therefore, everyone should prepare to change the level of his

system in the near future. Some published articles describing a company's change over to 12 kv are more guarded in their opinions. They may state that a change over was good and economically justifiable for a specific case or for a certain section of the system but this should not be generalized to take in all parts of the system or all utilities. Still other articles might be construed as a warning. Because continuity is a function of feeder loading, among other things, 12 kv can cost more than 4 kv if feeder loading is limited to an arbitrary value. This conclusion is usually based on an economic study that does not recognize the savings that can be realized using a 200 ampere recloser at 12 kv instead of metalclad switchgear. This may modify the economic study to some degree.

Economic Studies

Economic studies that have been made utilizing theoretical areas show that distribution system costs are influenced by load density and allowable feeder loading. These studies show that the economical choice may be 12 kv at light load densities. One important factor in favor of 12 kv at the light densities is the opportunity to use and load larger substations. We are using 3750 kva and 5000 kva unit substations at 12 kv while to cover the same area at 4 kv would require more substations in smaller sizes and higher cost per kva. The studies also show that the economical choice can change to 4 kv as the load density increases. This may come about by attempting to load feeders to an arbitrary standard. As load density increases, long and heavily loaded feeders are required to make 12 kv economically attractive. Again continuity and the matter of judgement will play an important part. Still, there is a range of densities where 12 kv distribution systems are more costly than 4 kv no matter how the feeders are loaded. Extended use of 12 kv may reduce equipment prices and help reduce this cost difference. The economic studies show small differences over a wide range in densities. The exception is when a 12 kv feeder load is limited by service standards in the medium density range. This appears to be a costly practice. Considering the frailty of cost estimates and the small cost differences shown by the studies it appears that, within reason, it is difficult to make a costly mistake. This line of reasoning could certainly apply to a new system but when the cost of changing from 4 kv to 12 kv is considered, more than a small difference in cost will be required to make the change over attractive.

Cost Comparison

Because the distribution system is made up of so many variables, theoretical economic comparisons between 4 kv and 12 kv must try to recognize costs from the customer through the subtransmission. When these costs are broken down, it is apparent that the 12 kv system has an obstacle to overcome in cost of distribution transformers. At light to medium densities, the 12 kv system can overcome this obstacle by offering savings in the subtransmission, in the substation, in losses or in conductor size. The savings may be some combination of these items but probably not all of them simultaneously. At higher densities the difference in distribution transformer costs becomes troublesome for the 12 kv system while the savings in subtransmission and substation become less until the 12 kv system costs more than the 4 kv system. Again, any effort to increase reliability by limiting feeder loading or by sectionalizing will be an added cost to the 12 kv. Studies have shown that at light densities, feeder loading may be limited to favor reliability and still the 12 kv system will show savings.

Reliability and Maintenance

It has been stated that our company has made limited use of 12 kv and that most of it has been installed in the outlying regions of light load densities. The general feeling is that operation has been good. There is still, and probably will continue to be, some differences of opinion as to whether working the 12 kv system with hot line tools is as satisfactory as working the 4 kv with rubber goods. No statistics are available as yet concerning the reliability of the 12 kv system. Since the 12 kv feeders have been limited in load, it is felt that reliability should be as good as at 4 kv. Whether the experience gained in the outlying districts is indicative of what could be expected in crowded high density areas is also open for discussion.

Conclusions

In attempting to arrive at some reasonable conclusions with the wealth of information at hand, two conflicting bits of advice are brought to mind. These are,"Do not use first design that gives technical excellence", and "Stop looking and start building". It appears that opinions still vary concerning 4 kv and 12 kv. There are favorable and unfavorable aspects to each. Any comparison involving the economics of 4 kv and 12 kv distribution systems must be concerned with costs from the customer through the subtransmission. The overall economics will understandably be greatly affected by the existing system. Cost differences as shown by economic studies are slight, expecially when considered in the light of the accuracy of estimates. There are, however, load densities where 12 kv costs appreciably more than 4 kv if feeder loading is limited arbitrarily. The higher voltage has some cost advantage in light density areas, but as the density grows, this advantage may be overcome.

In view of the slight cost differences, it is difficult to accept the added cost of change-over to replace a working 4 kv system with a 12 kv system. This is especially true if it is foreseen that the reliability aspect will have a predominant effect on the 12 kv system and therefore reduce the savings in number of feeders, sites and congestion at substations. The idea that the change-over cost will be prohibitive is subject to exception. An important factor in change-over is the cost of increasing conductor size at 4 kv vs using existing conductor at 12 kv. A portion of a system may contain many miles of #6 and #4 copper or equivalent primary conductor. Continuing at 4 kv could mean replacing miles of these sizes with larger conductors, much under hot line conditions, and all at high cost. Conversion to 12 kv permits such conductors to be adequate for a long time.

There are differences and exceptions but by our own admonition, we must "get building". What is the solution? In general, a combination of 4 kv with 34.5 kv subtransmission appears more economical and able to handle the growing load in the metropolitan area. There is concern in some quarters that such a choice will, with increasing densities, make for terrific congestion in distribution substations and lines. If adoption of a higher voltage will cure the situation, perhaps time and advances in the art will reduce 34.5 kv to a distribution voltage. This opinion is influenced by the fact that our present metropolitan system is largely 4 kv and 34.5 kv. Use of 12 kv is a better solution, though, for our suburban and rural areas and to make an integrated system in such areas, we are changing towns to 12 kv. In general, the solution will be to study and become familiar with the various areas comprising the power system. If particularly heavy weight should be given to any of those factors that make 12 kv appear attractive, then 12 kv should be used even though the existing system is largely 4 kv. No matter what the choice, it is believed that if we apply reason, we cannot go far astray.

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FAULT PROTECTION FOR THE UNION ELECTRIC SUBTRANSMISSION AND RURAL DISTRIBUTION CIRCUITS

By Ren Beatty and
I. F. Krughoff
Both of: Union Electric Company of Missouri

For Presentation at the 1956 Technical Conference for
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R. G. Zook
Assistant Administrator

FAULT PROTECTION FOR THE UNION ELECTRIC SUBTRANSMISSION AND RURAL DISTRIBUTION CIRCUITS

Ren Beatty I. F. Krughoff

I. INTRODUCTION

The purpose of this paper is primarily to discuss Union Electric practices and experiences related to the protection of subtransmission and rural distribution circuits, rather than general protection theory and practices.

II. RURAL DISTRIBUTION AT 12.47 KV

The Union Electric Company of Missouri began to use oil circuit reclosers and sectionalizers in quantity in the year 1948. At the end of 1955 there was a total of 833 reclosers and 547 sectionalizers in service on the Missouri System. It is estimated that there are approximately 50 reclosers in service in the Illinois territory, mostly operating at 4160 volts. There are approximately 166 reclosers and 34 sectionalizers in operation in the Keokuk area. Our Company first began to use the all porcelain-clad type recloser which has a mechanical type operating and timing system. Later on, when the hydraulic type reclosers became more available, we began to use them in fairly large numbers.

Our experience with the rural line recloser system has been very good. This is evidenced by the continued growth of our system and by conversion of existing 4160 volt systems to higher voltage distribution systems using line reclosers at the substations and on the circuits for sectionalizing.

It is our practice to install at the supply substation hydraulic type reclosers set for 4 operations on the steep retarded time curves. Farther out on the circuit, for sectionalizing, we use similar reclosers set for two fast and two extra retarded operations, as well as numerous sectionalizers. We also apply fusing in such a way that the line reclosing devices will protect the fuse on the first two operations and be protected on the third operation by the blowing of the fuse for a permanent type fault. Our rural type stations vary in capacity from 500 kva single phase to a proposed maximum of 7500 kva three phase. Larger stations will use relays and circuit breakers. High side protection is obtained by the use of 34.5 kv fuses.

III. SUBTRANSMISSION AT 34.5 KV AND 69 KV

(1) 34.5 Kv Supply to Distribution Substations

The 34.5 kv substation buses have a total load capability varying from 25 mva to 200 mva. The maximum short circuit is at present being limited to slightly less than 1,500 mva symmetrical.

The majority of the 34.5 kv feeders are being protected by three time overcurrent phase relays and one time overcurrent ground relay, all with instantaneous trip attachments. On the feeders supplied from the heavy buses, the instantaneous phase elements are set at 300 to 500 mva pickup and the instantaneous ground elements are set at 50 to 100 mva pickup. Thus, where

possible, all 34.5 kv faults in excess of 5,000 amperes are cleared in 10 cycles or less (60 cycles basis).

Pickup settings on the time-overcurrent ground relays are determined principally by coordination requirements. Pickup settings on the time-overcurrent phase relays are determined partly by the maximum load current. This has caused difficulty in detecting minimum phase faults on long feeders where heavy "close-in" load is being supplied. These conditions have been corrected as much as possible either by sectionalizing fuses or by not placing heavy "close-in" load on long feeders except in extreme emergency. Reactance or impedance type distance relays are of little use in discriminating between minimum fault currents and maximum load currents because there is so little bus voltage drop during minimum faults. Modified distance type relays are being considered for use on this type of feeder to discriminate by means of the difference in power factor between maximum load current and minimum fault current.

Since the majority of our 138/34.5 kv substations are unattended, automatic reclosing is used on the feeder breakers. A typical feeder reclosing duty cycle is: Open + 0 sec. + CO + 120 sec. + CO + 175 sec. + CO (lockout). It might be pointed out at this time that on some 4.16 kv and 12.47 kv distribution feeders, the first trip is by instantaneous relays but the succeeding trips are by time delay relays, in order to protect fuses on the first breaker opening but to produce fuse opening on or before the second breaker opening. At 34.5 kv, however, each successive trip is instantaneous, if within reach of the instantaneous relay element. Therefore, the 34.5 kv sectionalizing or load tap fuses must be small enough to clear during the first clearing time of a feeder breaker being opened by an instantaneous relay.

The following, for example, is a discussion of considerations required when selecting a primary fuse for a 34.5/12.47 kv transformer substation:

> In the matter of coordination, it has been found that there are generally four items that must be considered in the selection of the high voltage fuse for the primary protection of a delta wye transformer, as generally used in a 12.47 kv system. These are:
>
> 1. Full load current.
> 2. Interrupting duty.
> 3. Total clearing time for a phase to ground fault on the 7.2/12/47 kv bus.
> 4. Minimum melting time of fuse to backup the station type reclosers for locking out at maximum phase-to-phase fault duty.
>
> Sometimes when a fairly large transformer is being supplied from a limited primary source (i.e. high impedance source), it is necessary to limit station recloser sizes in order to effect coordination.

As previously mentioned, frequently it is advantageous to permit the subtransmission instantaneous type protection to reach beyond fuses. When this occurs, we attempt to size the fuse so that it will clear during the first operation of the subtransmission circuit breaker. Automatic reclosure then restores service.

It is our practice to use silver link type fuses for all subtransmission fusing (34.5 kv up). Their high degree of accuracy plus minimum susceptibility to damage (no short time rating needed) permits a much closer fusing tolerance for a good overall operation of the fuse-relay system. Our experience has been very good.

Conductor damage at 34.5 kv must be considered in determining desirable fault clearing times. Even with the setting of 5,000 amperes pickup on the instantaneous relays, some conductor burning is being experienced. Most of the open circuits have occurred either at clamp connections where additional heating occurs or at points where the conductor had been previously weakened by a fault arc. This condition may ultimately require either the use of faster opening breakers or limitation of the reclosing cycle. At the present time it is expected that rehabilitation of the circuits involved will decrease the number of burndowns.

(2) 34.5 Kv and 69 Kv Supply to Bulk Load Customers

In some cases the relaying at our feeder breakers may be the same as on feeders supplying our own distribution substations. Where a number of breakers are effectively in series, however, it is advantageous to use distance type relays with a definite reach for each definite time delay. This usually permits a faster time setting at the breaker closest to the source of supply. Such distance type relays are often imperative on the customers 34.5 kv or 69 kv subtransmission feeder breakers when located at a substation supplied directly from our 138 kv transmission system. If the customer's relays are too slow or if the reach and operating times are affected by current magnitude, coordination with our transmission line relays becomes more difficult.

Where the bulk load customer can supply "back-feed" to our system, additional relays are required at the tie point. Since the contract generally does not call for any reverse load flow, a time-reverse power relay, set to operate at a few percent of tie capacity, will suffice. In some cases, it may be desirable to supplement the reverse power relay with an under-frequency relay which operates faster the greater the frequency drop. Such an under-frequency relay is primarily for protection of the customers system, whereas the reverse power relay also provides fault protection for faults in our transmission system.

IV. CHECKING PERFORMANCE OF PROTECTION

(1) Reclosers

It has always been the policy of our Company to test the line reclosers when they are received new. We feel that our experience has borne out this decision in that we have found numerous defects in the new reclosers as

received from the manufacturer. The items found vary all the way from failures of new reclosers to operate, filings in the mechanism, incorrect timing sequences, wrong coil sizes, cracked coil bobbins and operating times that exceed the manufacturers' guarantee. It is our belief that our policy of testing new reclosers has brought about a number of improvements on the reclosers as manufactured.

A distribution standard has been written on the subject of the maintenance of reclosers and sectionalizers that are in service. A copy of the maintenance section of the standard follows:

> "Reclosers and sectionalizers should be inspected and the oil changed once each year or after 100 operations which ever shall occur first. Counters should be read at least once every six months to determine if the reclosers are operating excessively or have operated 100 times or more. If it is known that a recloser has operated a number of times under heavy duty faults it should be inspected and the oil changed immediately regardless of the number of operations since the last inspection.
>
> "A record by districts should be kept of all sectionalizers and reclosers installed on distribution lines. This record should indicate the ampere rating, serial number, date of installation and dates of inspection of each unit. In addition, recloser records should list the number of operations at each inspection.
>
> "Reclosers and sectionalizers can be inspected and the oil changed at each district repair shop if proper facilities are available, or they may be returned to Stores to be sent to the Relay Shop of the Meter and Relay Department for a complete inspection. However, any recloser or sectionalizer having been in service for three years or 170 operations since it has been inspected by the Meter and Relay Department should be returned to Stores to be forwarded to the Relay Shop of the Meter and Relay Department for a complete inspection and rehabilitation if necessary. Also, any unit which appears not to be operating properly should be turned in to Stores to be forwarded to the Meter and Relay Department for repair.
>
> "The Meter and Relay Department, after inspecting and repairing the unit, will stencil the date inspected on the outside case of the recloser and will reset the operations counter to zero. The sectionalizer will have the date inspected only stencilled on its case.
>
> "A report of each recloser or sectionalizer failure should be made and sent to the Distribution Standards Group. This report should indicate the location at which the recloser failed, number of operations since it was last inspected, date of last inspection, nature of failure and the serial number of the recloser or sectionalizer."

The recommendations as outlined in the above standards have been determined from past experiences and, of course, will be corrected from time to time as experience indicates. Refer also to the following paragraph on testing.

When we first began to test line reclosers, we recognized immediately that it would be necessary to develop test methods and devices preferably for testing the reclosers on 60 cycle current. As a result of this, we built a special test device initially for testing the mechanically operated timer type recloser. Improvements in the factory recommended test procedure were obtained in that it was possible for us to set up a system whereby the recloser could be tested without having to install a special contact and follower for the initial testing. We were able to test the device without having to dismantle the contact mechanism. Later on when the hydraulic devices were purchased, the test equipment was readily adaptable to testing this type recloser.

Once the recloser is set up on the test device and proper settings of the variacs and/or rheostats are determined, it is only necessary for the operator to operate a toggle switch to start the time cycle recorder and another toggle switch to pickup the main contactor to supply simulated fault current to the recloser device. After the recloser operates to the lockout point, a paper tape is obtained showing the complete operating sequence of the recloser. A welding time recorder is used for obtaining this tape. The recorder is not oscillographic but does count the individual cycles of current. Inasmuch as some of the times are fairly long, we do not make a practice of counting the individual cycles but have a scale that is used for measuring the length of a given portion of the record from which the time can be read directly. This has been sufficiently accurate for general use.

New reclosers as received are not uncrated for testing. Old reclosers that come back into our Stores Department are untanked, cleaned and inspected. Any defective parts are replaced; they are then reassembled with new oil, after which they must pass the same test as a new recloser. All reclosers are high potted at 25 kv, 60 cycle from live parts to ground and from bushing to bushing with the device open. At the time of the final testing, the Veeder Counters are reset to zero. Also, the month and year of the inspection is stenciled on the tank.

As a matter of interest, a tabulation of defects found on new and used rural line reclosers since 1948 is attached as Data Sheet "A".

A summary of sectionalizer and recloser lockout operations from 1948 to 1955 is indicated on Data Sheet "B".

(2) Protective Relays

Testing of our protective relays is done on a routine schedule. Instantaneous and induction types are normally checked for calibrations and physical condition annually. More complicated relays such as distance, differential, etc. are checked at intervals of six to nine months. Complete load checks are made on all relays by measuring phase and residual currents. Phase

relationships are checked on the more complicated type. Tripping checks proving complete continuity of all trip circuits are regularly made also. During these tests target operations are verified. On more complex systems involving many trip combinations, a dummy breaker is used to prove trip circuit continuity and target operations.

On new installations all protective phases are checked. These involve current and potential transformer ratios, polarities, excitation tests of current transformers and continuity of all physical wire circuits to the relays. Tripping and target operations are checked. After the equipment is in service, load and phase angle checks are completed.

(3) Oscillograph Records

The Union Electric Company has a total of nine oscillographs in service on the system and one is on order. One is a so-called portable unit for use at any location.

The permanently installed units are nearly all on the transmission system, although some elements are in service on subtransmission circuits.

The portable unit is used for any investigative activities and frequently is used on investigations on the subtransmission circuits.

The attached oscillogram shows the effectiveness of expulsion gaps in bypassing lightning strokes on a subtransmission circuit. This shows a total of at least ten expulsion gap operations in a period of approximately one second. The upper trace is the 34.5 kv neutral current in one of two source transformers.

Other records obtained during faults show operating times of the protective system. Switching sequences are also indicated as well as voltage drops and fault magnitudes. The latter is frequently used to locate faults particularly on transmission and higher voltage subtransmission circuits.

RenB/dd

DATA SHEET "A"

TABULATION OF DEFECTS FOUND IN SHOP ON NEW AND USED RURAL LINE RECLOSERS SINCE 1948

NEW

Timing off - 64

Wrong number of operations to lockout - 7

Wrong reclosing cycle - 22

Failure to lockout - 1

Moving contacts dropped off - 1

Broken bushings - 4

Erratic mechanism operation - 4

Metal filings found in mechanism and tank - 6

Trip counter inoperative - 2

USED

Incorrect trips by thermal device - 3***

Cracked coil bobbins - 3

Dielectric failure in service - 14

Possible miscoordination because of oil viscosity - 1

Growing cement at bushing flange - 3*

Control relay contact failures - 6

Contact follower fiber swelled - 1**

Failures to interrupt - 5

Total all items - 147

Total reclosers in service end 1955 - 1049

Total sectionalizers in service end 1955 - 581

* All recloser bushings of this type were replaced with new bushings to eliminate any further failures in the field.

** One positive, several suspected.

*** All thermal devices were removed.

DATA SHEET "B"

SUMMARY OF SECTIONALIZER & RECLOSER OPERATIONS

1948 - 1955 (NINE MONTHS)

Year	Line Sectionalizer Lockout	Line Recloser Lockout	*Station Recloser Operation
1948		28	5
1949	19	45	26
1950	55	28	47
1951	115	69	160
1952	60	53	141
1953	76	66	145
1954	141	131	158
1955 (9 mo.)	80	88	163

* Total number of operations counted even when recloser locks out. (i.e. a lockout of three phases counts 12 operations.)

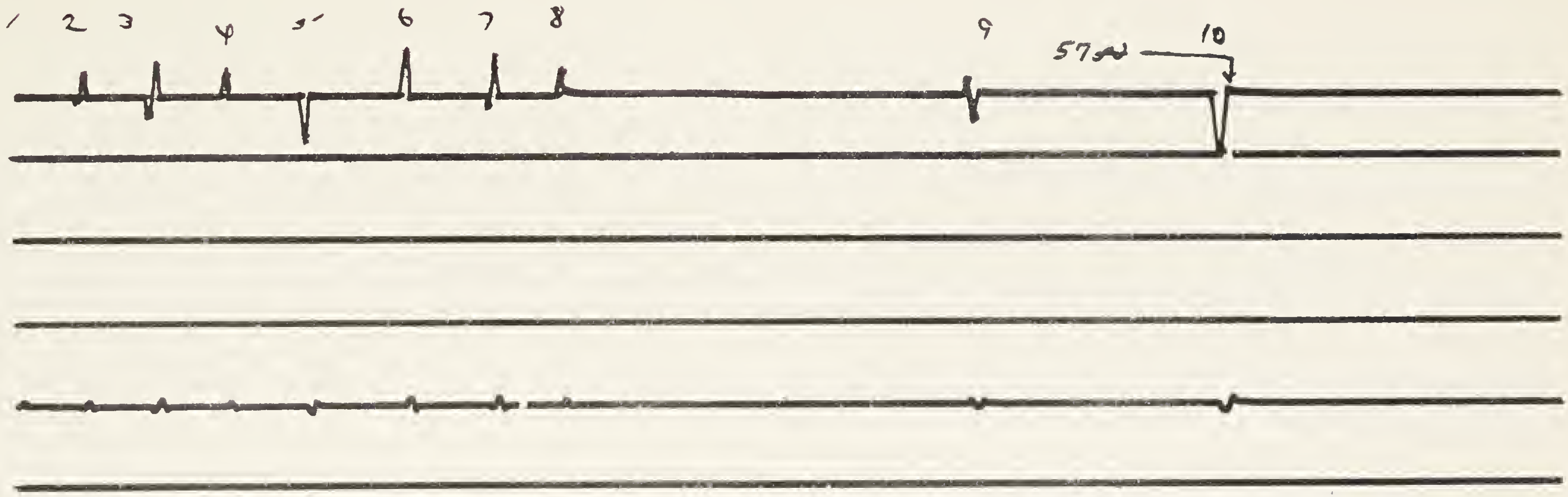

Fig. 1. Oscillogram of expulsion gap operations. Win-French Village 34.5 kv circuit. 7-31-54

TRANSMISSION LINE MAINTENANCE

By George W. Couch and
M. G. Cox
Both of: Union Electric Company of Missouri

For Presentation at the 1956 Technical Conference for
REA Field Engineers, Saint Louis, Missouri
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To assure freedom for the development of ideas which may serve to improve the engineering of rural electric systems, the authors of papers and discussions have been encouraged to explore new ideas and new techniques and to prepare papers which reflect their own engineering judgment and experience. Such an approach may develop ideas which deviate from industry practices and REA policies and procedures presently in effect. It should be recognized, however, that REA policies and procedures as set forth in REA bulletins are still applicable unless changed in the light of the ideas and experience which may result from such papers or discussions.

R G Zook

R. G. Zook
Assistant Administrator

TRANSMISSION LINE MAINTENANCE

George W. Couch   M. G. Cox

Nowhere does the adage of a "stitch-in-time" apply more aptly than to transmission line maintenance - which includes right-of-way maintenance as well as that of the lines themselves. A transmission line, together with right-of-way easements, represents not only a major investment which should not be permitted to deteriorate beyond economic repair, but adequate electric service depends on its condition and dependability during wind, ice, or lightning storms, or at times of transient electrical troubles.

These comments are based on the authors' experience in the maintenance of 1000 miles of transmission lines of several voltages up to 230 kv. These lines run some hundreds of miles from the company's Osage hydro plant in mid-Missouri to St. Louis, to the lead belt area in southeast Missouri, to St. Louis, to the Keokuk hydro project in Iowa, and into central Illinois. These lines traverse major urban areas, cross some of the richest farm lands in the United States, cross several times our two major rivers, the Mississippi and Missouri, and traverse some hundreds of miles through forested and rough Ozark country.

LINE MAINTENANCE

Line maintenance falls into three aspects: (a) Routine patrols to reveal incipient trouble; (b) Normal maintenance on a small local trouble spot, or a large line-length problem, as a result of such patrols and inspection, and (c) Emergency location and repair of trouble. The third, emergency repairs, are also facilitated by the knowledge of roads, paths, creeks, and possible trouble spots learned through both routine or emergency patrol work.

Routine patrols should be based on a carefully scheduled program found to be adequate from experience. The authors have found that patrols both by air and by foot (the latter helped by automobile, of course) have their place.

Regular airplane flight patrols are contracted by this company. These are now set up for monthly inspection of each line, supplemented by specially scheduled inspection after unusual exposure such as wind storms or sleet. A study has been made of helicopter service for the same purpose; our present preference is for the low flying two seater plane. Experience over the past ten years has borne out the value, dependability, and economy of air line patrol. This success applies in both level farm country and in rugged mountainous areas. The pilots doing this work must be trained so as to observe quickly the key points of possible trouble over each type of line they fly. We have had excellent results both as to cost per mile of line patrolled, and accuracy of reports from air line patrol. The reasonableness of this can be judged by photographic views taken from a patrol plane.

The pilot is equipped with two-way radio, and can thus communicate cases of either normal or emergency trouble with a minimum delay to the central transmission office console. Weather, wind, and terrain must be well understood by patrol pilots, and field training and experience are of top importance.

A Work-to-be-Done-Log has been utilized to transfer the results of patrol inspections into specific orders for field correction.

Ground patrolmen, working on foot or from cars, are suited particularly for lower, low voltage lines. Here access by road is a heavy factor in patrol costs. Since a great portion of high tension lines are through rugged, wooded country, patrol by foot is scheduled for twice a year. For fast patrol in emergency situations walkie-talkie radio equipment is helpful.

A much discussed point is how fast patrol by car can be most efficiently conducted. In the authors' opinion this depends on the nature of the line patrolled, traffic conditions and the skill of the patrolman. In any event adequate instruction, car, radio, and good maps are valuable tools.

Maps. Adequate maps, careful marking of special access roads and paths, and a logical tower numbering and circuit marking have all proven to be essential aids to transmission line patrol and maintenance. The authors have been developing some of their own maps using geologic survey and county plats to good advantage. A carefully accurate marking of small streams and creeks has been found to be particularly important. Streams not only show limitations in truck moving operations, but give indication of slope of the long, dry ridge, parallel lying land over which roads or driving lanes can be figured out. It has been helpful to mark all low lying creek spots subject to flood in high water. This can save many miles of useless retracking. These latter are shown particularly on the detail maps kept on the system.

Radio communication has been greatly facilitated in the Missouri-Iowa-Illinois area served by a system of microwave towers supplemented by local radio communication. This system in the Union Electric Company has been previously reported, and need not be reviewed again here, except to again state that it has proven to be a high quality, highly dependable, and quite economic system. Our only serious troubles have been associated with layout of towers. In several instances our surveys, based on ground elevations, proved to be inadequate for tower height determination and tower heights had to be increased 50 ft or more after tree and other interference was found to affect performance.

Maintenance of lines is largely a matter of organization and transportation equipment. Trucks adequate to traverse the country involved, and sufficiently equipped to affect adequate field work without delay or return trips, are the essential of a good line maintenance operation. We have developed a bolster turning trailer for moving long poles, say 90 ft, through narrow streets of cities, or over narrow, wooded areas. This device, similar to the firemen's hook-and-ladder arrangement, has its turning table held and made adjustable by bolts.

Interesting economies have been effected in one of our major repair jobs, the replacement of 4 x 4 oak cross arm tension members in a 120 mile line from Rivermines to Osage. A shop for turning out these oak arms has proven to be an effective arrangement. Arms are dried, aged and treated in this shop facility. Over the past three years some 3000 arms have been made for this particular job, at a major saving over outside purchase.

RIGHT-OF-WAY CLEARANCE

No field of transmission line maintenance has been receiving more attention in recent years than that of clearance of trees and brush under high voltage lines

passing through non-farming areas. Chemical spray by ground equipment, by plane and by helicopter are all useful. Chemical spraying has developed both some major advantages and has had some disappointing failures. Repeated spraying to produce the claimed percent of kill has been found necessary in many cases.

A serious by-product of air spraying has come from damage to neighboring growth or crops due to chemical spray carried by wind drift. It is typically quite difficult to measure the true extent of damage done, or the accurate dollar value of crop or tree growth so damaged.

A device which this company has found to be particularly effective for large scale brush clearance is a tractor towed flailing machine. This unit, best described by photograph, and better seen than described, consists of heavy flailing weights swung outwardly and centrifugally from a revolving drum suspended between large diameter carrying wheels. Up to one and one-half acres of 8 to 10 year hardwood growth can be cleared each hour of operation. Oak trees up to two inches in diameter can be so felled. The growth is reduced to a mulch and ground blanketing-cover quickly becoming part of the soil. There has been no adverse fire experience, or ground erosion problems, and the clearance remains effective for periods upward of six or more years.

Maintenance of wood pole structures in Missouri would not be complete without reference to pole top damage caused in nest building by the pileated woodpecker. This large bird has moved northward into south Missouri in recent years, and has done great damage. Its nest, near the pole tops, is 6 to 9 inches in diameter and up to 30 inches of depth. Once the damage is this far, only replacement of the pole will do. Plugging or covering the entrance early in its formation is the remedy, but this is more easily talked about than achieved in this territory. A patch job has been effective. It can be applied where three inches of pole shell remain. This consists of plugging up a partial size hole with a mixture of paving asphalt and portland cement. A plug from another pole shell is cut to fit the entrance hole, is driven in and sealed with plastic cement.

In summary, transmission line patrol, and maintenance, whether routine and normal or in emergency, is a very special field. It calls for organization and equipment. It is greatly facilitated by good maps and good communications. As in all other phases of the electrical business, to this problem we are bringing modern methods ranging from the airplane to chemistry, and certainly including equipment of our own design to meet specific conditions of terrain and weather.

LOAD DISPATCHING IN UNION ELECTRIC SYSTEM

By J. K. Bryan, Mechanical Development Engineer
J. F. McLaughlin, Betterment Engineer
L. A. Mollman, Power & Communications Supervisor
All of: Union Electric Company of Missouri

For Presentation at the 1956 Technical Conference for
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Assistant Administrator

LOAD DISPATCHING IN UNION ELECTRIC SYSTEM

J. K. Bryan, J. F. McLaughlin and L. A. Mollman

The Union Electric System and its two subsidiaries, Missouri Power & Light Company and Missouri Edison Company supply service in a large part of the State of Missouri and smaller parts of Illinois and Iowa. Figure 1 shows the territory served. Union Electric as shown supplies the major metropolitan areas around St. Louis, but also includes the Keokuk and Fort Madison areas to the north, the Rivermines and Crystal City industrial areas to the south and the area surrounding its hydro plant in the center of Missouri.

This paper on "Load Dispatching" will confine itself to the Union Electric System only since its load dispatching is not coordinated with that of its subsidiaries except to a very limited extent. Figure 2 is a more detailed picture of the Union Electric System and shows more of the major transmission lines as well as the power plants. It also shows the points of interconnection and the points of delivery to other utilities. Union Electric supplies power to 18 utilities, cooperatives and municipalities.

Seven steam plants and two hydro plants constitute Union Electric's generating capacity of about 1,600,000 kw. This year's instantaneous maximum load was 1,395,000 kw and this occurred in July. It is expected that system peaks will continue to occur in the summer due to the steadily increasing acceptance of summer air conditioning. Only a major change in the use of electric power can change this trend.

Represented among the seven steam plants of the system is a wide range in flexibility, operating cost and age of equipment. At one extreme is the Venice No. 1 plant with a capacity of 40 mw. Equipment in this plant was installed between 1910 and 1930 and is now highly inefficient by modern standards. The plant utilizes premium fuel (oil and gas). Venice No. 1 is a peaking plant used very infrequently.

At the other extreme is the new up-to-date Meramec Plant. Here there are two units with a total capacity of 280 mw, one installed in 1953, the other in 1954. The turbines in this plant utilize steam at a pressure of 1250 psi and 950°F, and employ reheat, also at 950°F. Fuel used is principally coal with some natural gas burned on a dump or interruptible basis. The Meramec Plant requires a little less than one-half the amount of fuel that Venice No. 1 requires to produce a kilowatt-hour. Because of its high efficiency, this plant is base loaded and at present produces 20-25% of the total Union Electric generation.

Other plants include the historic Cahokia Power Plant on the Mississippi River across from St. Louis. This plant, the first in the country to be built for use of coal in pulverized form, has a capacity of 325 mw in six units. These units were installed during the 1920's and 30's and have steam conditions of 325 psi at 700°F. Cahokia now has a load factor of about 40%; it is required on peak each day and operates at minimum load during the night and weekends.

The workhorse of the system has now become the Venice No. 2 Plant, also located on the Mississippi River across from St. Louis. Built during the 1940's, this equipment is relatively modern and efficient. With 500 mw capacity, it

represents the largest single block of generating capacity of the system, although the Meramec Plant will exceed it in size when a 250 mw unit now being installed goes into operation in 1958. Venice No. 2 has six machines and eight large-size boilers operating at 850 psi and 900°steam conditions. During 1954, Venice No. 2 produced almost one-half of Union Electric generation. Fuel, again, is principally coal, with provisions for accepting natural gas when available.

Union Electric's oldest plant is Ashley, a combination electric and steam heating plant. Units totaling 73 mw capacity date back to 1917 and 1921, although a new boiler plant was built immediately before and following World War II. Because of this plant's low steam conditions of 200 psi and low efficiency, it has a low load factor.

The remaining two steam plants are the 40 mw Mound Plant equipped to burn oil or natural gas and a 15 mw plant operated by Union Electric in conjunction with the Granite City Steel Company Plant at Granite City, Illinois.

The steam plants are located in or close to the St. Louis Metropolitan District.

The two hydro plants located at Keokuk, Iowa and at Bagnell, Missouri differ decidedly in characteristics. The Keokuk Plant, a low-head plant on the Mississippi is essentially a run-of-river plant with little storage possibility or peaking capacity. This plant went into operation in 1913 as a 25 cycle plant with 15 units and approximately 130 mw optimum total capability. Six units have been converted to 60 cycle operation during the past few years and one of the two original 110 kv 25 cycle transmission lines connecting it to St. Louis has just this past year been converted to a 138 kv 60 cycle circuit.

The Osage Plant at Bagnell which impounds the waters of the Lake of the Ozarks, is a storage type plant of 8 units with an optimum capability of 215 mw with a maximum head of about 100 feet. It is connected to St. Louis as shown on the map by 2 circuits direct to St. Louis, 2 by way of Rivermines and Crystal City and 1 circuit connects it to Kansas City by way of Moberly, Missouri. The latter is a 161 kv circuit, the others 138 kv.

The Union Electric System is interconnected, as mentioned previously and as shown on Figure 2, with Kansas City Power & Light Company at Moberly, Missouri, with Central Illinois Public Service Company at East Quincy, Illinois, with Illinois Power Company at their Wood River Plant and at Union Electric's Venice and Cahokia Plants. Central Illinois Public Service Company, Illinois Power Company and Union Electric constituting what is known as the Illinois-Missouri Pool are also interconnected at West Frankfort, Illinois with Electric Energy, Inc. and their Joppa Plant at Joppa, Illinois.

This Illinois-Missouri Pool was formed simultaneously with the conception of Electric Energy, Inc. a corporation set up to supply a large part of the load of the Paducah Atomic Energy Plant in cooperation with TVA. Electric Energy, Inc. is owned by the Illinois-Missouri Pool members and Kentucky Utilities Company and Middle-South Utilities Company.

The Illinois-Missouri Pool was formed to allow the three utilities to pool their generating facilities, their reserves and whatever other advantages might be had by interconnection such as the possibility of installing larger generating units to obtain lower per kw costs and better efficiencies. The contract providing

this pooled interconnection is very flexible and any operating problems are readily handled by an Operating Committee. Another major purpose for forming the Pool was to allow it to supply power to the AEC plant prior to the time the Joppa Plant of Electric Energy, Inc. was completed.

Since EEInc and TVA operate in parallel to supply the AEC load and since TVA for many years has been in the interconnection composed of most of the utilities in the eastern and southern part of the United States, Illinois-Missouri Pool's interconnection with EEInc made them a part of this major interconnection. At the same time, this brought Kansas City Power & Light Company and the United Pool, of which it is a part, also with this major network because of the interconnection at Moberly, Missouri.

Last May another major tie was closed between the United Pool and Omaha Public Power District. The latter had already been interconnected with the previously mentioned major interconnection by way of the utilities in Nebraska, Kansas, southwestern Missouri, Oklahoma, Arkansas, Louisiana and Kentucky to TVA. This closure at Omaha and Council Bluffs, therefore, closed a 1600 mile loop.

Load Dispatching for the Union Electric System presented an entirely new problem with the advent of interconnection. Prior to this the Load Dispatcher's primary job was to maintain system frequency, to allocate the load economically to the plants of Union electric and to handle the switching and protection of the major transmission system as well as the subtransmission system in the City of St. Louis. After the major interconnection the system frequency was the result of the interconnected system operation. His generation capacity of 1,600,000 kw was small as compared to the 35 million kw interconnected. His problem was still to load his plants on an incrementally correct basis, but also to keep his tie lines at their scheduled loading. This tie line schedule is now the result of his ability to buy from or sell to his neighbors if incremental or decremental costs so justify. Actually, he is now in continual contact with neighboring utility dispatchers making sales or purchases of power to the benefit of both utilities. This, of course, is another one of the major benefits of interconnection. During this summer it was not unusual for the Union Electric Load Dispatcher to buy 175 mw of power while he still had more than this available on his system. He could buy it for less than his generation cost.

It would be practically impossible for the Load Dispatcher to maintain tie line loading schedules and system capacity without automatic load control equipment to assist him. Automatic load control was put into operation in the Union Electric's Load Dispatching Office about $2\frac{1}{2}$ years ago, at the time when the Illinois-Missouri Pool connection was made to Joppa Plant but before interconnection into the major interconnected system. This equipment is now his "electronic brain".

The basic purpose of all load control equipment now used by practically all utilities interconnected into the large network is to generate enough power to supply the area load plus the scheduled deliveries to others or less the scheduled deliveries from others. It bases its operation on its scheduled tie line load and accurate 60 cycle frequency. If the native load of the system increases, the first effect is to increase the take from the tie lines; the interconnected system supplies the first increment of increased load. This causes the load control equipment to send impulses to all plants on control to increase generation, thus bringing the tie lines back to schedule. The reverse is, of course, true if the

load decreases. This operation is continuously going on automatically in the load control equipment.

Since the automatic equipment must maintain or regulate this generation requirement, it is obviously necessary that it be set up to bring the plants into operation in an economical manner. Setting up the console of the load control equipment in the Union Electric System is the function of the Load Dispatcher. For this he uses the Incremental Costs supplied by the Betterment Group of Union Electric.

To accomplish economical division of load the dispatcher must know the incremental production costs of each steam plant throughout its load range. A brief description of how these incremental costs are developed may be of interest.

A first requirement before incremental costs can be developed is to know the efficiency characteristics of the individual steam turbines and boilers in all the plants. Normally, tests are made as equipment is added to the system and results reflect new equipment performance. Efficiency characteristics are plotted as input-output curves.

The incremental heat rate at any output is equal to the slope of the input-output curve at the point corresponding to that output. Mathematically, the incremental heat rate is the first derivative of the input-output curve with respect to output. Practically, it represents the additional rate of heat input required to pick up an additional kilowatt of load.

Consider a plant with 3 units, each having different performance characteristics. Let the incremental rates be represented by curves A, B, and C in Figure 3. It can be demonstrated mathematically that, to obtain the lowest fuel input to this plant the three units should be loaded to give equal incremental rates. This means that unit A will be brought on the line first and loaded until its incremental cost equals that of unit B. This occurs at 80 mw. Unit B will be brought on the line and take all increase in plant load up to the point where its incremental cost begins to increase. Units A and B will then share the plant load increases keeping incremental costs equal until plant load reaches 150 mw. At this load unit A will carry 90 mw and unit B will carry 60 mw. Unit C will then be brought on load and take all load increases until its incremental curve begins to increase. Units A, B, and C now share load increases according to their incremental curves. For example, at plant load of 210 mw loads will be divided 100 mw, 70 mw, and 40 mw for units A, B, and C respectively.

By this method a schedule of loading of all the units in a single plant can be developed such that the lowest possible fuel input is obtained. Once an economical schedule of loading is developed for both boilers and turbines, an input-output curve can be developed for the entire plant. Plant incremental heat rate curves are developed from the input-output curves. Curves A, B, and C in Figure 3 could just as well represent plant incremental curves. An economical loading schedule of plants could be developed as shown for individual turbines. Knowing fuel costs, incremental maintenance costs, and incremental heat rates, incremental costs in cents per kwh are easily calculated. Input-output curves are periodically adjusted for deviation of actual efficiency from test efficiency based on actual monthly operating results. In Union Electric practice, plant incremental heat rate curves are broken down into load bands and the average incremental cost for each band is determined. These incremental costs and plant load bands are then

tabulated in the order of increasing incremental costs into what is called the "Incremental Cost Sheet".

This Incremental Cost Sheet is used by the Load Dispatching Supervisors as well as by the Load Dispatchers. It is used to schedule the generating plant requirements based on the estimated load. This is done by the supervisory staff and supplied to the Load Dispatchers prior to quitting time on the day before the estimate.

All estimates are calculated from the base load of the same day of the prior week. This base load is the result of correcting the actual load of that day to exclude the effect of cloudiness and interchange with others. The new estimate takes into consideration the predicted temperature plus or minus the schedules with neighboring utilities. Experience and a continuous record of load changes with light factor changes allows the supervisory staff to estimate a reasonable clear day load. The supervisory staff allocates this estimated load to the various power plants based on the incremental costs mentioned before. As soon as the Load Dispatcher receives this estimated load allocation he informs the various plants so that they can schedule units, boilers, coal and manpower to make this estimated requirement available the next day.

At six o'clock in the morning the Load Dispatcher gets a new prediction of cloudiness and temperature for the day. He immediately corrects the load estimate and the estimated requirements from the plants and informs them of this change.

Figure 4 shows a typical Union Electric Summer load curve. On it are shown the hourly loads allocated to the various plants, all based on the incremental costs. This particular allocation assumes good hydro conditions. Hydro is base loaded and is, therefore, at the base of the load curve. Immediately above hydro are the various incremental cost bands of the various steam plants, the lowest cost bands, of course, being at the bottom. Figure 5 is the same load but assumes hydro as for peaking operation. In this case the run-of-river, Keokuk Plant, is base loaded since it must operate more or less equal to river flow. Its peaking effect and the entire Osage Plant are used at the top of the load curve to handle the peaks, allowing the steam plants to be essentially base loaded. The steam plants are again shown by incremental cost brackets.

The Load Dispatcher use the estimated schedules to set up their automatic load control console in their office on a current basis. This equipment once set up, automatically controls the generation requirements of the plants for quite some time. As mentioned previously, it will load and unload the plants in accordance with the changes in the area load. It will contribute towards maintaining a 60 cycle frequency as well as hold a scheduled tie line load.

During times of trouble external to the system it will assist the interconnected system in arresting frequency changes and in maintaining sufficient capacity to supply the load. If a major case of trouble such as loss of a unit should occur in the Union Electric System, the first effect is that the tie lines will supply the deficiency. The automatic load control then will immediately bring on all of the available spinning reserve capacity in the system. If this is insufficient to supply the load the tie lines will continue to supply the deficiency. It is then the responsibility of the Load Dispatcher to immediately bring on more of his available capacity or schedule additional power from neighboring utilities. He must not allow this to flow into his system unless it is scheduled and, therefore, paid for.

By virtue of being interconnected into the major system network it is also necessary for the Load Dispatcher to regularly police the tie line delivery or receipts. Errors in meters have a large effect on the accuracy of the load control equipment because the equipment cannot sense these errors. The result is an inadvertent flow which must be kept to a minimum.

The Load Dispatching Department of the Union Electric System, like that of any other utility, is really the nerve center of the system. It is responsible to management for the proper scheduling of load to the various plants on an incremental basis as well as to constantly make the most beneficial deals with the neighboring utilities.

In order to do this there must be proper communication facilities. In the Union Electric System all forms of communication are in use - microwave, power line carrier, telephone line carrier, V.H.F. radio, private wire and Bell leased lines. Figure 6 shows the microwave network. It supplies voice communication to Kansas City, Decatur, Illinois, Pana, Illinois, Joppa, Illinois, as well as to some Union Electric Plants. It is also used for channels for load control functions on several of the plants and for control of the V.H.F. radio associated with the transmission system. Carrier Current equipment is used for voice communication to Keokuk and for some load control functions. Bell leased lines are used almost entirely for both communication and load control in the immediate vicinity of St. Louis, the location of the Load Dispatching Office.

All voice communications made available to the Load Dispatchers are terminated in two cabinets adjacent to the dispatching desks. All such circuits are direct circuits, not available for any other purpose than dispatching.

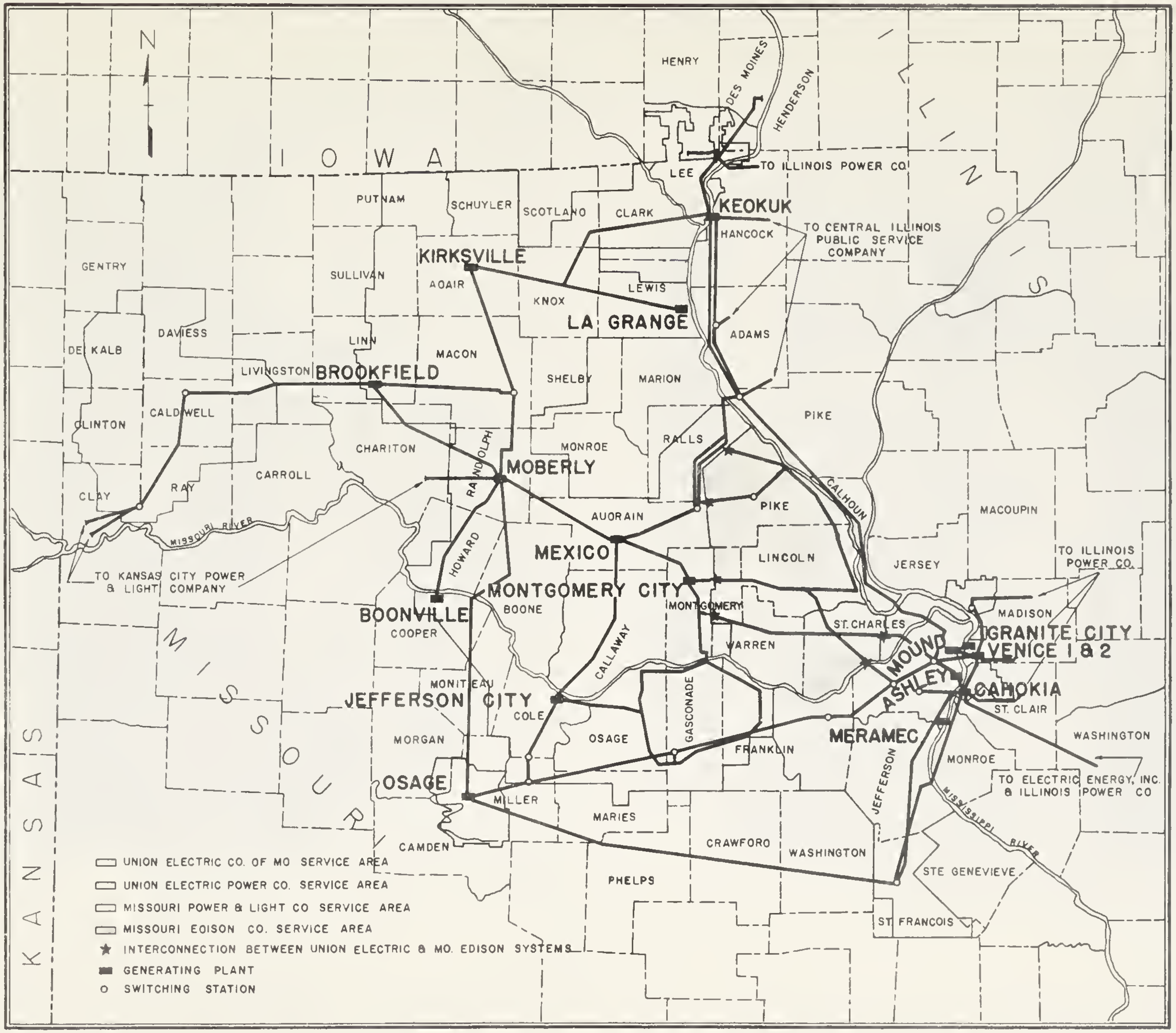

Fig. 1. Map of service area of
Union Electric System and subsidiaries

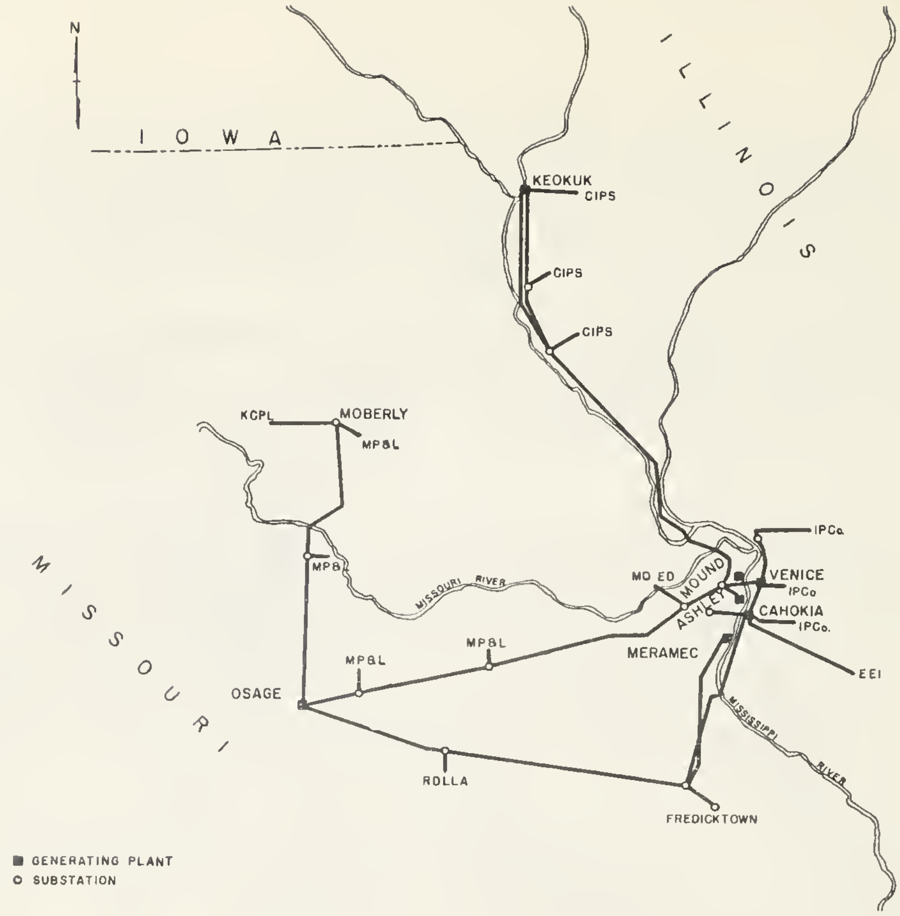

Fig. 2. Major transmission lines and interconnections of Union Electric System

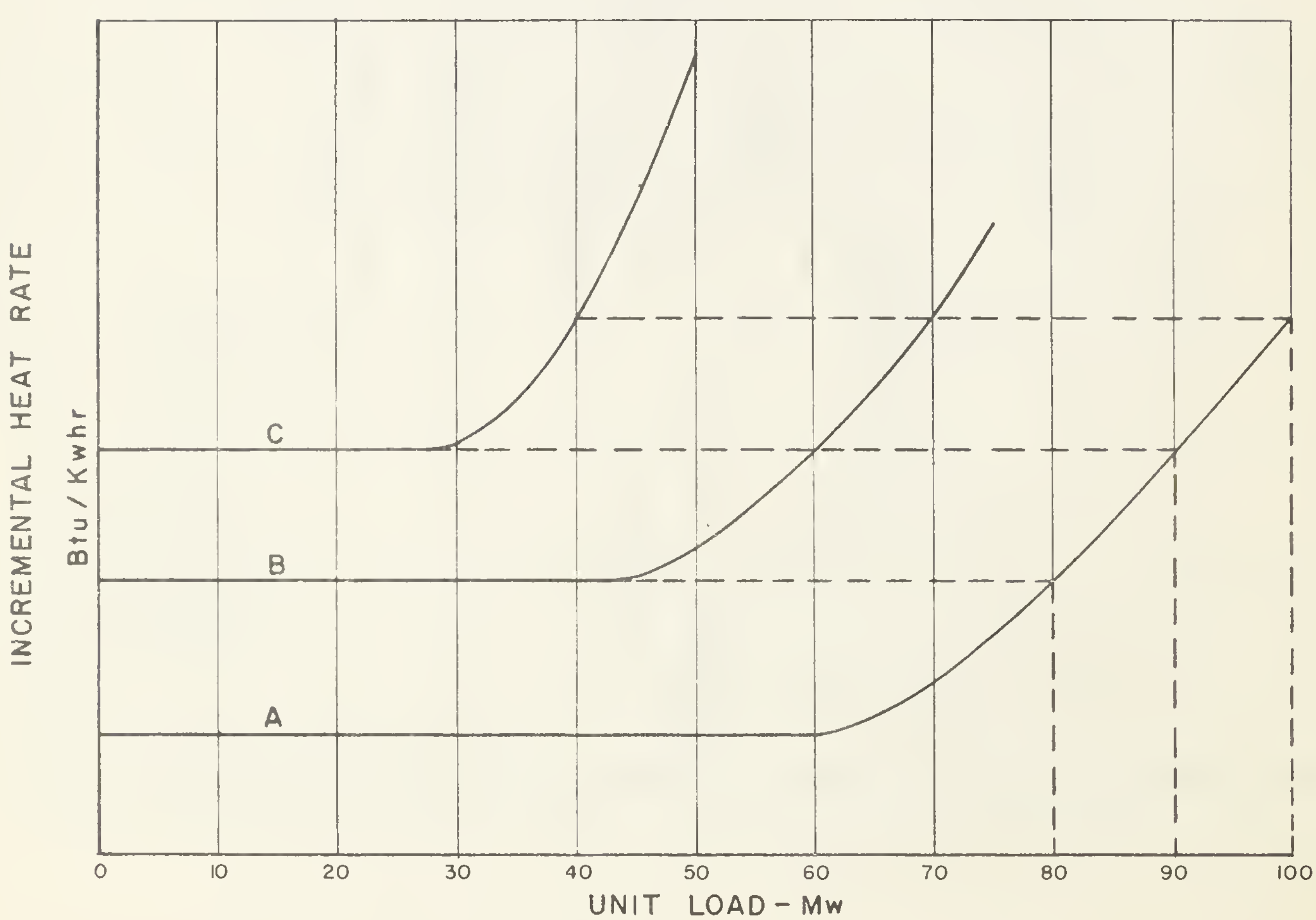

Fig. 3. Incremental loading of units

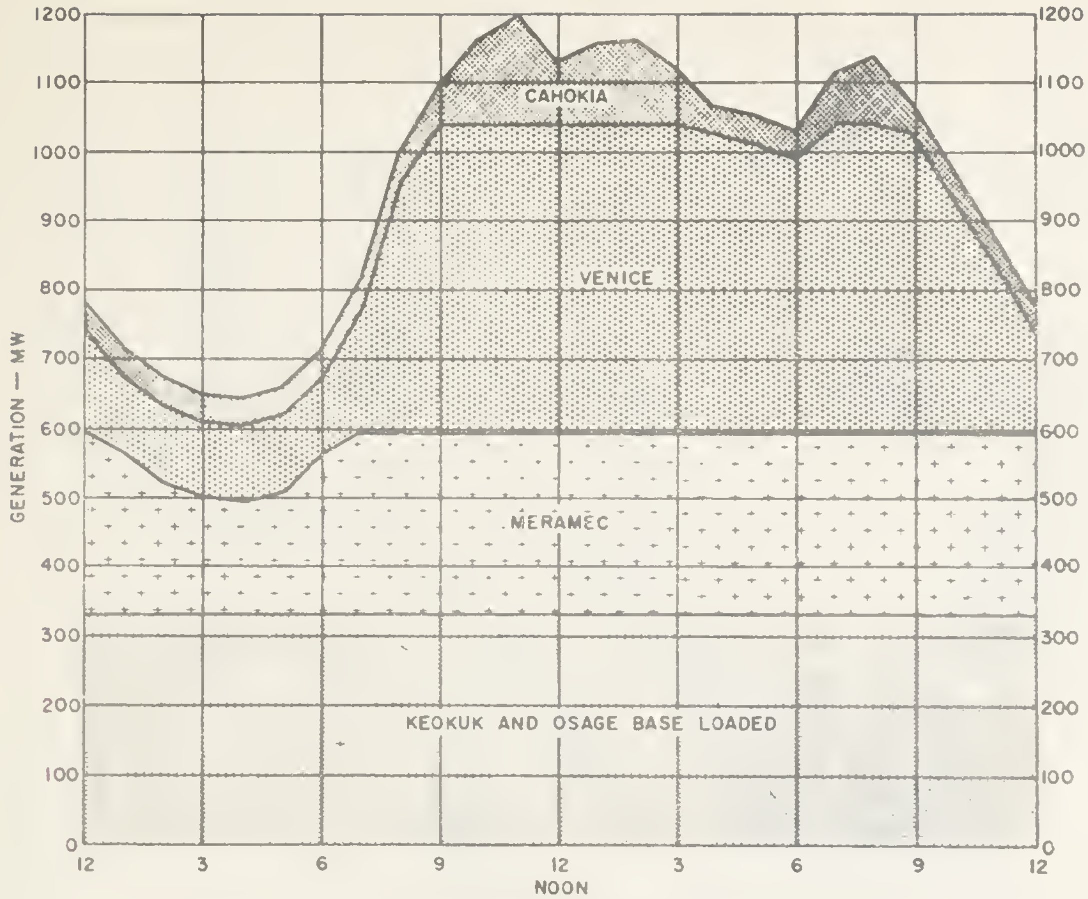

Fig. 4. Typical April 1955 generation distribution-hydro base loading

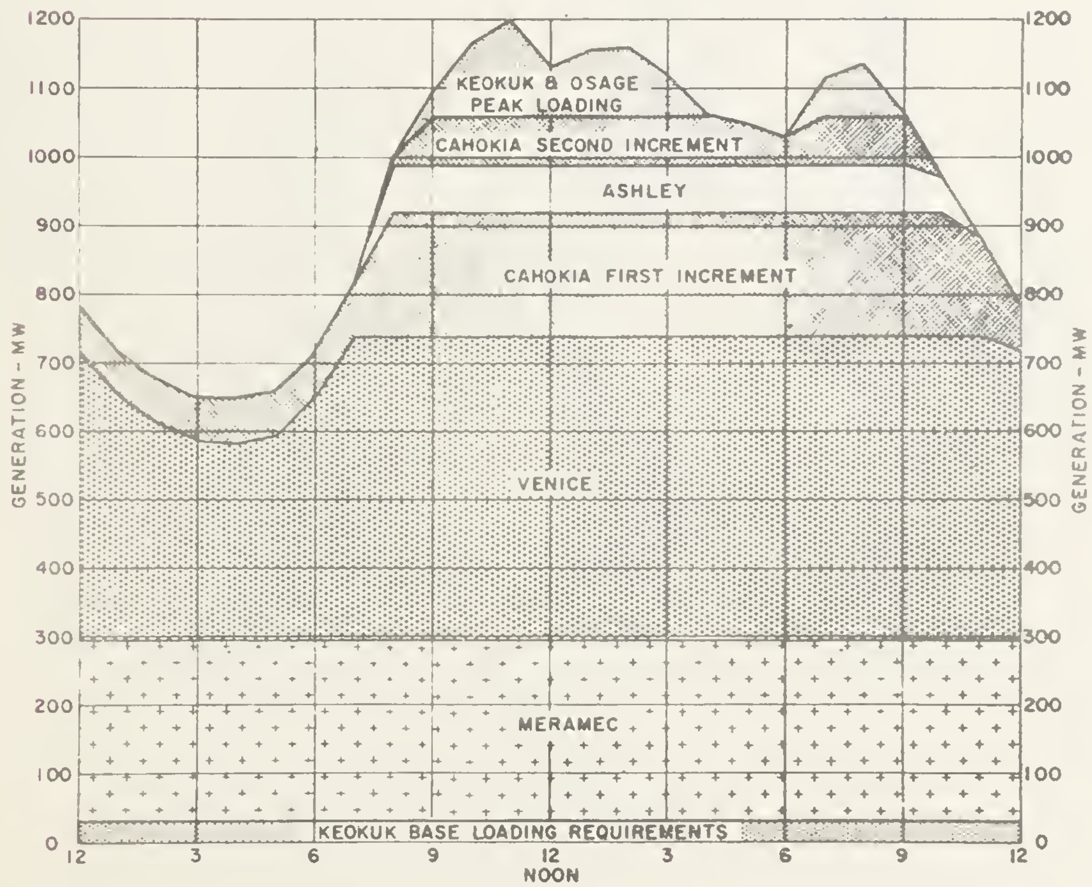

Fig. 5. Typical April 1955 generation distribution-hydro peak loading

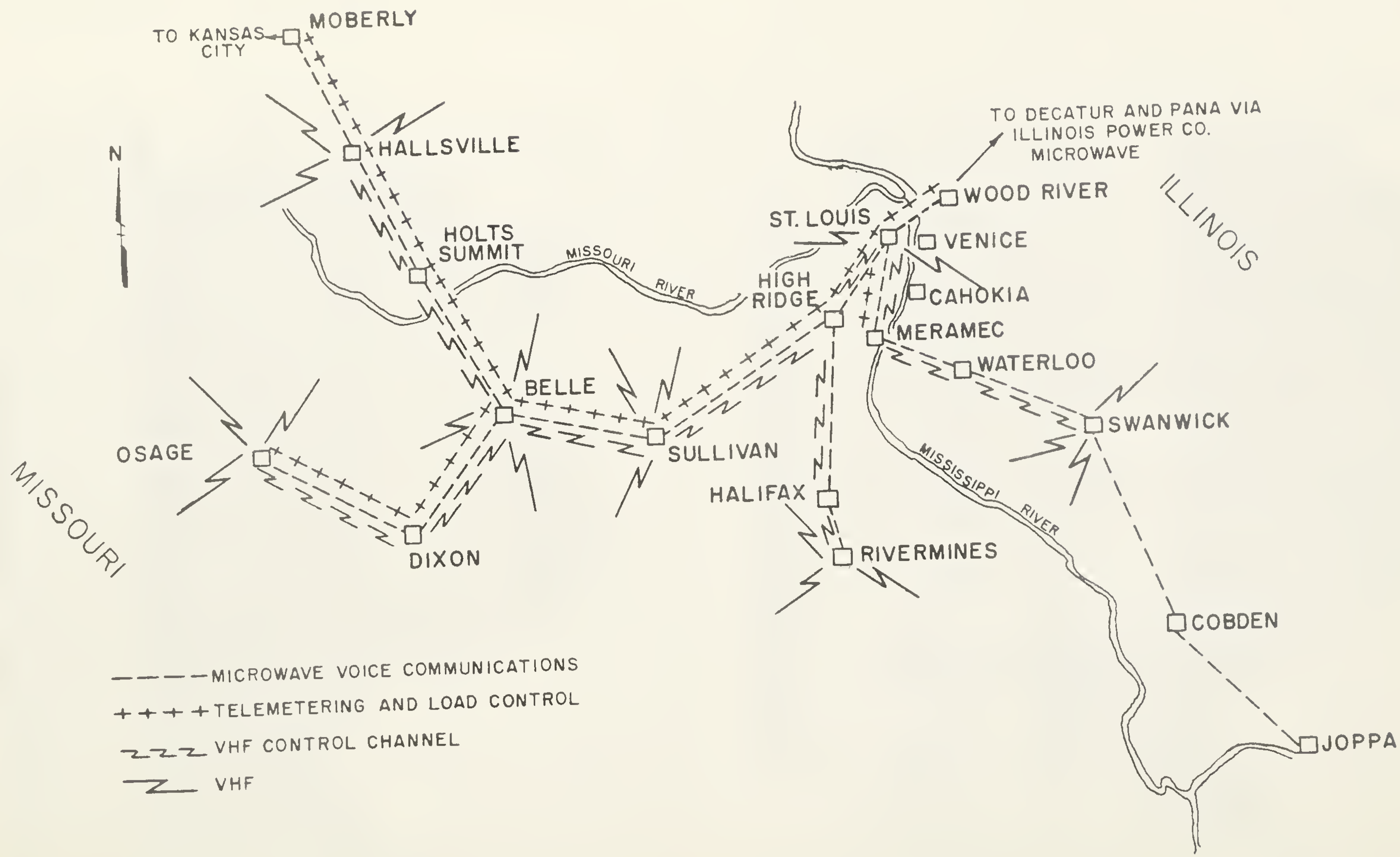

Fig. 6. Microwave circuits of Union Electric System

SERVICE TO LARGE MOTOR LOADS

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For Presentation at the 1956 Technical Conference for
REA Field Engineers, Saint Louis, Missouri
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REA

U. S. DEPARTMENT OF AGRICULTURE

RURAL ELECTRIFICATION ADMINISTRATION

ABOUT THE CONFERENCE .... The purpose of the Annual Conference for REA Field Engineers is to provide a forum for the discussion of engineering matters concerned with rural electric systems. The objective is to make available to field engineers an opportunity to share views and experience with other engineers who have developed a high degree of experience and specialization in specific fields. Likewise, the objective is to provide the specialist engineer with an opportunity to share his views with those who are facing the practical daily engineering problems.

To assure freedom for the development of ideas which may serve to improve the engineering of rural electric systems, the authors of papers and discussions have been encouraged to explore new ideas and new techniques and to prepare papers which reflect their own engineering judgment and experience. Such an approach may develop ideas which deviate from industry practices and REA policies and procedures presently in effect. It should be recognized, however, that REA policies and procedures as set forth in REA bulletins are still applicable unless changed in the light of the ideas and experience which may result from such papers or discussions.

RG Zook

R. G. Zook
Assistant Administrator

SERVICE TO LARGE MOTOR LOADS

INTRODUCTION

The increased use of electricity in farm operations and the establishment of small industries in rural areas are creating electric service problems not normally associated with domestic use. These problems involve motor loads of all types, both single-phase and three-phase. The starting torques and other load characteristics are of every conceivable magnitude. In fact, the extreme ranges of utilization requirements prohibit formulation of any one set of rules or guides applicable to all.

This paper has been prepared to summarize and present possible solutions to some of the most common problems associated with motor loads.

PHASE CONVERTERS

For many years, practically since the beginning of three-phase power, engineers have attempted to find an inexpensive, reliable method of converting balanced three-phase to single-phase. An equal amount of effort has been expended in the attempt to reverse the process -- to obtain three-phase power from a single-phase source. Either of these conversions is readily accomplished by means of a rotary converter. As these devices are essentially motor-generators, they are expensive and have limited application.

The aim of recent development has been to provide means of operating three-phase motors from single-phase sources. Because of the physical arrangement of the stator windings of a three-phase squirrel cage induction motor, it is possible to operate the motor from a single-phase source. This is accomplished by introducing a phase shift in the supply voltage to one winding of the motor, meanwhile supplying normal single-phase power to the other two motor terminals.

It has been stated that the motor can be induced to operate. Its quality of operation is another matter. If the voltage magnitudes and phase shifts can be made equivalent to those of a three-phase supply, the motor will operate identically with true three-phase power. Under these conditions the conversion is 100% effective as the substitute supply is providing the motor with balanced voltages and currents at all magnitudes of motor loading. Unfortunately, a 100% conversion, as herein qualified, is not obtainable with reasonable cost. For this reason, each type of phase converter offers some compromise in motor operational results.

There are two basic types of static phase converters presently available. One employs a straight capacitor type phase shift; while the other uses a transformer-capacitor combination to obtain the phase shift. A brief review of the overall characteristics of these devices is as follows:

<u>Capacitor Type Phase Converter</u>: This device provides a phase shifted voltage to the motor by placing a capacitance in series with one phase lead of the motor winding. As the effective impedance of the winding at locked rotor is considerably different from that at full speed, different values of capacitance are necessary under the two conditions. This type converter switches a bank of electrolytic capacitors into the circuit during the starting cycle. They

are switched out by a voltage sensitive relay (or a time delay relay) as the motor approaches full speed. This leaves a bank of oil filled capacitors in the series circuit during the running cycle.

The capacitor type converter can be balanced to provide equal voltages and correct phase angles at one running condition -- when the motor power factor is 50% or lower lagging. This operating power factor can be achieved only under a no-load, or very lightly loaded, condition. This does not imply that the motor becomes inoperative when loaded beyond this point. It does mean that motor currents will be unbalanced with reduction in torques normally associated with those magnitudes of currents. The motor will operate without overheating approximately to the point of nameplate current rating. However, the motor will not be producing rated torque. An analysis of the motor circuit could show that two opposing torques are present: (1) A positive torque as a result of the positive sequence (normal) voltages and currents and (2) a negative torque due to the negative sequence (vectors representing the unbalance) voltages and currents. As the normal torque is reduced by a factor representing the degree of unbalance, the horsepower output is likewise reduced.

An installation of a capacitor type converter and three-phase motor must be carefully tailored to the load requirements. After the load horsepower and starting torques have been determined, the converter-connected motor should be selected at least one motor size larger than the nameplate rating would indicate. This derating is not just a cautious move. The motor characteristics have been altered sufficiently to make it a requirement.

Transformer-Capacitor Type Phase Converter: This device employs an autotransformer to raise the nominal single-phase voltage before it is applied through a series capacitor to the third motor lead. This transformer is usually equipped with several taps to permit selection of the suitable voltage to obtain a balanced condition. As in the capacitor type phase converter, this device employs an auxiliary bank of capacitors to provide the correct phase shift for starting. These are removed by a relay during the running cycle. After the motor has reached rated speed and is carrying the load, the motor is checked for balanced voltages and currents. If they are not balanced, the motor is shut down and changes made in the transformer and capacitor taps to obtain better balance. Repeated changes may be required before the motor voltages and currents are within commercial tolerances.

After a motor has been balanced for a particular load, it will remain in balance as long as the supply voltage (single-phase) and load remain constant. Changes in either of these two quantities will affect the supply to the motor. However, small variations in load or voltage input will not seriously unbalance the motor currents. If the motor is operating at rated load or less, the currents will not exceed the nameplate rating.

Caution must also be exercised in applying this type of converter. If starting torque requirements are severe, the motor may have to be selected one size larger than the nameplate rating would indicate.

Special Unit Type Converter: One manufacturer, which also produces a transformer-capacitor type phase converter, has introduced a specially designed motor and capacitor type converter combination. By designing a polyphase induction motor

with unbalanced windings and unusual phase angles between windings, the manufacturer states the motor and phase converter combination will operate as a very efficient, high torque, unit. The motor is not suitable for direct application to either single-phase or three-phase circuits. It must be used in combination with the special phase converter. Properly installed, the combination unit is claimed to provide up to 200% starting and breakdown torques.

The combination of the phase converter and a standard polyphase induction motor changes the full-load slip characteristic drastically. The combination acts as if the motor rotor were of extremely low resistance with correspondingly low slip. To counteract this characteristic, the manufacturer of the special motor and capacitor phase converter combination has incorporated a high resistance rotor in the motor. This provides a slip characteristic comparable to the standard polyphase motor.

The special unit of motor and converter has just been introduced to the market. It is offered in the range from one through 30 horsepower. Care must be used in the application of the larger units as single-phase primary circuits may be taxed to handle the high horsepower requirements.

IRRIGATION MOTORS

The rapid expansion of farm irrigation has brought forth a series of electrical problems peculiar to this application. These difficulties range from failure to obtain coordination of the motor overcurrent protection to the creation of a reversal of phase rotation on part of the distribution system. Not all the difficulties are caused by the pumping installations. Some are the result of other factors indirectly related to the electrical application. The type of primary switching employed, the transformer connections and method of grounding can influence the type of troubles that may appear in an irrigation load area.

Selection and Coordination of Motor Overcurrent Protection: It is universal practice to purchase motor starters with two overcurrent devices. Where primary circuit switching is done on a three-phase basis, this is very satisfactory. However, where primary switching is done with single pole reclosers or fuses, it is possible for a motor to burn out without tripping either of the two overcurrent devices. This can be explained by saying it is caused by a combination of positive and negative sequence currents adding vectorially to produce excessive current in only the unprotected phase of the motor. The best insurance against this type of failure is the installation of an overcurrent element in each phase of the motor. Starters with three overload elements are obtainable from most manufacturers at a slight additional cost over the type having two elements.

The installation of three overcurrent elements in a starter does not solve all the problems associated with these devices. Many of the current sensitive elements are of the thermal type. A consumer may order and install a starter with the correct elements for the motor. However, practically all irrigation pumping installations are made with no shed or housing over the equipment. This means the motor starter is exposed to direct sunlight. As the result of this sunlight exposure, high ambient temperatures and accumulated heat due to load currents, the thermal elements generally derate themselves to a much lower value. This means a motor may trip out even though it is operating at less than full load. When this condition occurs, a consumer is likely to replace the overload elements with others

of higher rating. He has exchanged protection from "too much" to "too little". The motor now has improper overload protection except during the highest ambient temperature interval.

The solution of this problem can be accomplished two ways: (1) Shield the starter from direct sunlight and provide good ventilation about the enclosure. These steps may be all that is necessary to correct the trouble. (2) Change out the thermal overload elements to those of the magnetic type. Magnetic overloads are less sensitive to ambient temperature changes and should retain better calibration. The change-out to magnetic trip elements may require an auxilary enclosure to house the elements. This will complicate the installation and should be used only if the other remedial measures fail.

Phase Reversal on the Distribution System: Occasionally, it is observed that motors run backward as if the phase rotation on the system had been reversed. There is a possibility that this is the case. Omitting phase reversals caused by mechanical switching errors and supply reversals beyond the control of the borrower, it is possible for the irrigation motors, under single-phasing conditions, to establish a phase reversal on the distribution system. It is an established fact, once started, a three-phase induction motor will continue to run and carry some load when energized from a single-phase source. It will generate its own three-phase voltage, supplying the unenergized phase with voltage having normal frequency and phase rotation but slightly reduced in amplitude. If the motor is running in its normal direction, the phase rotation will be normal. To obtain a phase reversal under these conditions, the motors will have to run in the reverse direction. The following case may reveal how this can happen:

Case: A borrower reported that loss of a high-side fuse on a substation (33 kv delta to 7.2 kv 4-wire wye) resulted in severe damage to two irrigation pumps on the system. They were started backward with rupture of couplings and shafts.

Analysis: An analysis of the voltage conditions that exist under the single-phasing conditions outlined above reveals that one phase on the distribution system would have normal voltage while the other two phases would have 1/2 normal voltage (all readings to grounded neutral). These are single-phase voltages with such polarities as to give phase-to-phase voltages of 0.866 normal, 0.866 normal and zero. The voltages on the secondary of a service transformer bank connected floating wye primary, grounded delta secondary would be normal, 1/2 normal, 1/2 normal, all single-phase.

Possible Results: Under these service voltage conditions, approximately 1/3 of the motors on the system would have the starter holding coils on the phase having normal voltage. All other motors would drop off the line as the holding coils would release under the 1/2 voltage condition. As some irrigation pumps are designed so they are not damaged under reverse rotation, motors on these pumps are seldom equipped with anti-reversing devices. The motors, still connected to the system, will not maintain normal horsepower output under the single-phase condition and will probably come to a stop. If the overload devices do not trip out, the motors will be started backward by the torque exerted on the impeller by the water running back down the well casing. Once started, the motors are practically

unloaded and will continue to run. If this happens, the initial voltage conditions are destroyed and the system has three-phase voltage, reverse phase rotation, with the motor energized phase voltage slightly lower than normal. Anyone attempting to restart a pump which had dropped off the system under the initial voltage conditions would find the pump starting backward under practically normal starting torque. If pumps are not designed for reverse rotation, this can result in severe damage such as dropping the impeller and shaft by unscrewing a coupling or rupturing couplings or shafts.

The above analysis is only one possibility of the cause of the trouble. However, the damage to some pumping installations is so great under reverse starting that mention should be made of devices that will prevent this from happening.

Anti-Reversing Ratchets: This is a mechanical ratchet that is incorporated in the motor drive assembly to lock the motor shaft to the frame if the motor is started backward or if the returning water attempts to drive the motor backward. Under reverse starting, the overcurrent devices would remove the motor from the circuit to prevent damage. This device is illustrated in figure 1.

Motor Release Coupling: This is also a mechanical device, figure 2, that releases the motor from the pump if the motor is started in reverse direction. As the direction of applied torque is the same for the returning water in the casing as it is for the normal drive of the motor, this device will not prevent the motor from spinning during the normal rundown of water in the well. Of more importance, this device will not prevent the motor from being started and run backward. It will merely prevent the motor from driving the pump backward. Motor release couplings are of no value in the phase reversal analysis used above. The motor will be rotated backward by the pump impeller, when it reaches sufficient speed to reverse the direction of torque, the coupling will separate and permit the motor to continue running with the pump disconnected.

Phase Reversal Relay: This device, figure 3, is an electrical relay that holds contacts closed as long as the phase rotation is normal. It will also open the contact under single-phasing conditions. As the control contacts are placed in series with the motor starter holding coil, the motor will be deenergized under either single-phasing of reverse phase rotation conditions. This device will prevent reverse phase rotation being established on the system by the motors and will also prevent reverse starting damage.

Stoppage of Motors on Temporary System Faults: One of the major complaints by irrigation users is centered around the water distribution system employed on the farm. Distribution of water to individual rows or multiple rows is sometimes accomplished by using syphons to transfer water from a main distribution canal to the laterals. If the irrigation pump stops for more than a few minutes, the water level in the main canal is lowered to such an extent that all syphons are broken. This means the pump and all syphons must be restarted after each oil circuit recloser operation that affects the starter holding coil. With good justification, the farmer considers this a lot of unnecessary work. He wants a device, some type of delay relay, that will hold the starter in the run position (or return it to the run position) during a portion of the coast down time of the motor. As this device must obtain its timing

when electrical energy is not present, it must have some means of storing energy to drive the timing element when the circuit is deenergized.

One solution to the problem is to by-pass the START contacts with a relay that keeps the starter in the run setting for a predetermined period of time after the circuit interruption. These time delay relays are available in spring return escapement, pneumatic spring loaded return, and thermal type. They should be purchased with adequate time range to suit local conditions. One special device for this purpose is shown in figure 4. Its function is accomplished by placing the holding coil under direct current control with capacitors supplying the energy for 4 to 8 seconds after circuit interruption. The timing can be changed by substitution of other values of capacitance.

MOTOR STARTING METHODS

Single-Phase Motors: REA has no requirements or limitations on horsepower sizes for single-phase motors. In the early days, it was suggested that single-phase motors be limited to five horsepower. Since the rural circuits in those days were low capacity and quite long, this suggestion was valid. In recent years, the circuits have been shortened and increased in capacity. It is now suggested that each borrower serve motors as large as the circuits will permit, consistent with voltage flicker characteristics of the load. If single-phase motors can be operated with across-the-line starting without serious voltage flicker, they should be permitted. If across-the-line starting is permitted, provisions should be made in the service contract with the consumer to require reduced voltage starting, when and if it becomes necessary.

Single-phase motors are now available in ratings as high as 15 horsepower. Some manufacturers are experimenting with 20 horsepower models which may be on the market in the near future. In general, these larger motors are capacitor-start, capacitor-run with good operating characteristics. They are not particularly suited to reduced voltage starting. However, they can be started by this method if the starting torques of the loads will permit it. As previously stated, one manufacturer of phase converters is now offering a combination of specially designed motor and converter in sizes from one through 30 horsepower. This device should be treated as a single-phase motor, with the locked rotor current obtained from the characteristics of the combination of converter and motor. Reduced voltage starting should not be applied to this device unless specifically recommended by the manufacturer.

Polyphase Motors: Three-phase motors should be applied in the same manner as single-phase motors. They should be served with across-the-line starting where possible. However, the power supplier should protect itself against poor operating practices and changes in circuit characteristics by specifying that reduced voltage starting must be installed if and when required. This will keep the consumer's investment to a minimum, comensurate with good service to all concerned.

Special Starting Devices: Recently, considerable interest has been created in special starting clutches for motor drives. Among these are trade names such as "BLM," "Electrofluid," "E-M Magnetic Drive," "Flexidyne," "Gyrol." They all operate on the principle of allowing the driving motor to reach a high percentage of full speed before the load is picked up. The manner in which the drive is transmitted varies with each type of clutch. Some are electromagnetic, hydraulic, pneumatic, friction shoes or friction pellets.

Drives in this category do not reduce locked rotor inrush current magnitude. The same initial inrush (starting) current magnitude will be measured on a drive equipped motor as would be present on an across-the-line start using conventional pulley and belt drive. However, the duration of the inrush current is reduced as the drive unit allows the motor to gradually bring the load up to speed. The time required for the locked rotor current to fall back to full load value will be determined by the characteristic of the load and the adjustment of the drive unit.

Human reaction to voltage flicker is a variable and is influenced by many factors such as frequency, amplitude, duration and time of day. There are probably many motor installations where the clutch drive units will prove satisfactory as a substitute for a reduced voltage starter. The power supplier should determine whether or not these drives are equivalent to the reduced voltage starters for certain type loads. If the drive unit is applicable, the power supplier should not specify that such drives be used; but, should make them an alternate to the starter.

The clutch drives are designed to aid motor users in several ways other than elimination of reduced voltage starters. Some of these are:

1. They can reduce shock loading on machine drives, thus reducing maintenance.

2. They can permit motors to break away on overloads, reducing motor burnouts and circuit interruptions.

3. They may permit starting high inertia loads with smaller motors, saving the user considerable in equipment costs.

4. They may eliminate the need for speed reducers (for starting).

It must be kept in mind that clutch drives are consumer equipment, similar to motors, speed reducers, starters and drive assemblies. These installations should be served where such services do not deteriorate the quality of service to other consumers.

FLICKER VOLTAGE*

Consumer Reaction: The calculations for voltage drop caused by motor starting currents are relatively simple. After these have been made and the magnitude of the flicker voltage is known, it has to be determined if the magnitude is sufficient to cause consumer irritation. Some estimates indicate that infrequent primary line voltage flicker could be as great as six volts (referred to a 120 volt base) and not result in a complaint. Infrequent flicker would include cases occurring six times or less in twenty-four hours, but not more than once between 6:00 p.m. and midnight. Where there is high motor saturation, such as an irrigation area, the magnitude of voltage flicker should be kept to a minimum for any one load, probably about three volts. Local experience is the best guide as to permissible levels.

The television receiver is one of the most sensitive flicker voltage indicators. The picture response is far more sensitive to sudden voltage changes than the best indicating voltmeters. If the distribution area has a reasonable saturation of tele-

*This material was developed by Roland W. Schlie,
Electric Engineering Division, REA

vision receivers, voltage flicker complaints are likely to be far more severe than in a similar area with no television.

In general, if calculations do not reveal voltage flicker levels beyond previous complaint-free installations, it should be safe to permit the load to be connected. If calculations show more severe flicker, caution should be used in supplying power to the applicant under the proposed starting conditions.

Flicker calculations: The general equation for the calculation of voltage drop is as follows:

$$\text{Voltage Drop} = I\ S\ (R \cos \theta + X \sin \theta) \qquad (1)$$

Where: Voltage Drop is expressed in volts

I = amperes per phase
S = line distance in miles
R = resistance of line in ohms per mile
X = reactance of line in ohms per mile
θ = angle between load voltage and current (Power Factor angle)

The power factor angles of motor starting currents are relatively low and vary considerably for the different types and sizes of motors. Normal starting power factors for induction motors up to 150 horsepower are shown in figure 5.

To simplify the equations, three nominal values of starting power factor, 0.30, 0.45 and 0.60 have been used to calculate the values of ($R \cos \theta + X \sin \theta$). If these values are designated as K, the wire constant, then the formula for any wire size and number of phases becomes:

$$\text{Voltage Drop} = I\ S\ K \qquad (2)$$

The following table illustrates the various values for K, the wire constant, for various configurations and wire sizes with spacings used on 7,200 volt and 14,400 volt circuits:

TABLE I

WIRE CONSTANT, K

Wire Size Cu. Equiv.	V-Phase & Single-phase			Three-phase		
Power Factor	0.30	0.45	0.60	0.30	0.45	0.60
8	2.5	3.0	3.5	1.9	2.4	2.8
6	2.0	2.4	2.6	1.4	1.7	2.0
4	1.7	1.9	2.1	1.2	1.3	1.5
2	1.4	1.6	1.6	1.0	1.1	1.2
1	1.3	1.4	1.4	0.91	0.98	1.0
1/0	1.2	1.2	1.2	0.86	0.90	0.92
2/0				0.80	0.83	0.83
3/0				0.72	0.74	0.73
4/0				0.68	0.69	0.67

The locked rotor current of a three-phase induction motor is between 580% and 600% of the rated full-load current of the motor. However, if the secondary circuit to the motor is correctly designed for up to 3% regulation at full load, the motor will not have rated voltage on its terminals under the locked rotor condition. If it is not supplied with rated voltage, it will not draw full rated locked rotor current. In other words, because of drop in supply voltage, there will be a drop in the starting currents.

To simplify equations and to approximate the conditions of locked rotor values, we can assume the following:

1. Primary rated current, full-load, of the motor is approximately equal to one-third the horsepower rating of the motor divided by the line-to-ground voltage in kilovolts: $I_{FL} = \frac{\text{Horsepower}}{3 \times 7.2}$

2. Locked rotor current of the motor will be 500% of the full-load current:

$$I_{LR} = \frac{5 \times \text{Horsepower}}{3 \times 7.2} = 0.23 \times \text{Horsepower} \qquad (3)$$

On V-Phase circuits, the phase current due to a three-phase motor load is the same magnitude as for full three-phase circuits. However, because of phase angles between the secondary currents and the primary currents, the neutral on a V-Phase circuit will have 1.73 times the phase current for balanced three-phase secondary loads. Thus, we have the following for V-Phase circuits:

$$\text{Phase } I_{LR} = 0.23 \times \text{Horsepower}$$

$$\text{Neutral } I_{LR} = 1.73 \times 0.23 \times \text{Horsepower} = 0.40 \times \text{Horsepower}$$

Voltage drop on the V-Phase circuit is approximately equal to the circuit constants multiplied by the average current. Therefore:

$$\text{V-Phase Current, } I_{LR} = \frac{(0.40 + 0.23) \times \text{Horsepower}}{2}$$

$$I_{LR} = 0.31 \times \text{Horsepower} \qquad (4)$$

On a single-phase circuit the phase (and neutral) current is approximately equal to the horsepower of the single-phase motor divided by the line voltage in kilovolts. Thus, we have:

$$I_{FL} = \frac{\text{Horsepower}}{7.2} = 0.14 \times \text{Horsepower}$$

Likewise: $I_{LR} = \frac{5 \times \text{Horsepower}}{7.2} = 0.69 \times \text{Horsepower}$ (5)

The simplified equations for voltage drop for locked rotor currents, equation (2), now become:

Three-Phase Circuits:

$$\text{Voltage Drop} = 0.23 \times HP \times S \times K \qquad (6)$$

V-Phase Circuits:

$$\text{Voltage Drop} = 0.31 \times HP \times S \times K \qquad (7)$$

Single-Phase Circuits:

$$\text{Voltage Drop} = 0.69 \times HP \times S \times K \qquad (8)$$

As the above equations are actually flicker voltages at the primary voltage level, we wish to refer the values to the nominal 120 volt base. This is accomplished by dividing the above quantities by 60, the transformation ratio for 7,200 volts to 120 volts. The equations then become:

Three-Phase: $\text{Voltage Drop} = 0.0038 \times HP \times S \times K \qquad (9)$

V-Phase: $\text{Voltage Drop} = 0.0052 \times HP \times S \times K \qquad (10)$

Single-Phase: $\text{Voltage Drop} = 0.0115 \times HP \times S \times K \qquad (11)$

If equations (9), (10) and (11) are applied to the various wire sizes, the result will be voltage drop, on a 120 volt base, per horsepower-mile. These values are shown in table II.

TABLE II

FLICKER VOLTAGE ON A 120 VOLT BASE
(MOTOR STARTING VALUES)

Wire Size	Volts Drop Per Horsepower Mile								
Cu. Equiv.	Single-Phase			V-Phase			Three-Phase		
PF	0.30	0.45	0.60	0.30	0.45	0.60	0.30	0.45	0.60
8	0.029	0.034	0.040	0.013	0.016	0.018	0.0072	0.0091	0.0106
6	0.023	0.028	0.030	0.010	0.012	0.014	0.0053	0.0065	0.0076
4	0.020	0.022	0.024	0.0088	0.0099	0.011	0.0046	0.0049	0.0057
2	0.016	0.018	0.018	0.0073	0.0083	0.0083	0.0038	0.0042	0.0046
1	0.015	0.016	0.016	0.0068	0.0073	0.0073	0.0034	0.0037	0.0038
1/0	0.014	0.014	0.014	0.0062	0.0062	0.0062	0.0033	0.0034	0.0035
2/0							0.0030	0.0032	0.0032
3/0							0.0027	0.0028	0.0028
4/0							0.0026	0.0026	0.0025

SAMPLE CALCULATIONS

The sample problem in figure 6 will illustrate the use of tables in determining flicker voltages from motor starting currents. As indicated in figure 6, there are five motor loads on one feeder, scheduled for across-the-line starting. In tabular form, the flicker voltage drops are shown below:

FLICKER VOLTAGE DROP CALCULATION

Motor Installation	Horsepower Miles	Circuit Used	Voltage Drop Constant (Table II)	Voltage Drop on 120 volt base Section	Voltage Drop on 120 volt base Total
B-50 HP 3Ø	500	#2-3Ø	0.0042	2.1	2.1
B-20 HP 1Ø	200	#2-1Ø	0.0180	3.6	3.6
C-30 HP VØ	300	#2-VØ	0.0083	2.5	
	150	#4-VØ	0.0099	1.5	4.0
D-25 HP VØ	250	#2-VØ	0.0083	2.1	
	125	#4-VØ	0.0099	1.2	
	200	#6-VØ	0.0120	2.4	5.7
E-15 HP 1Ø	150	#2-1Ø	0.0180	2.7	
	75	#4-1Ø	0.0220	1.6	
	120	#6-1Ø	0.0280	3.4	
	150	#8-1Ø	0.0340	5.1	12.8

NOTE: Voltage drop under running conditions will be slightly less than 20% of the values obtained for across-the-line starting.

Fig. 1. Anti-reversal Ratchet

Fig. 2. Motor Release Coupling

Fig. 3. Phase-reversal Relay

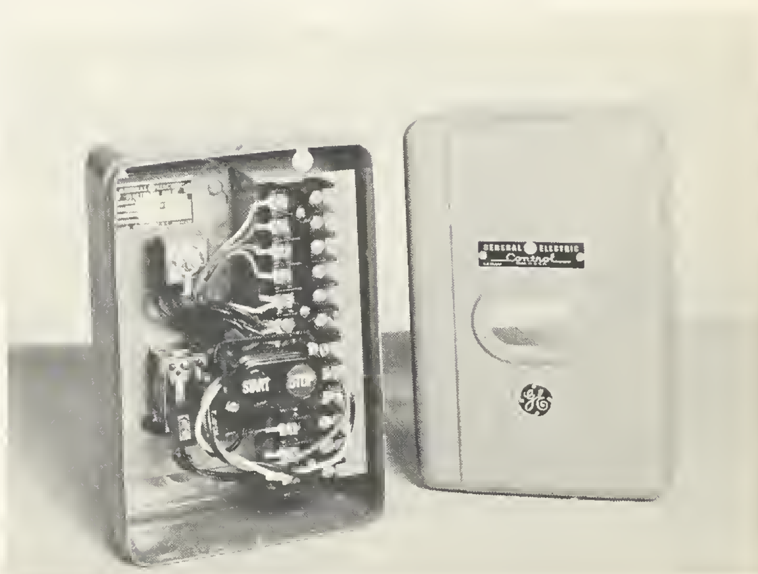

Fig. 4. Time Delay Station

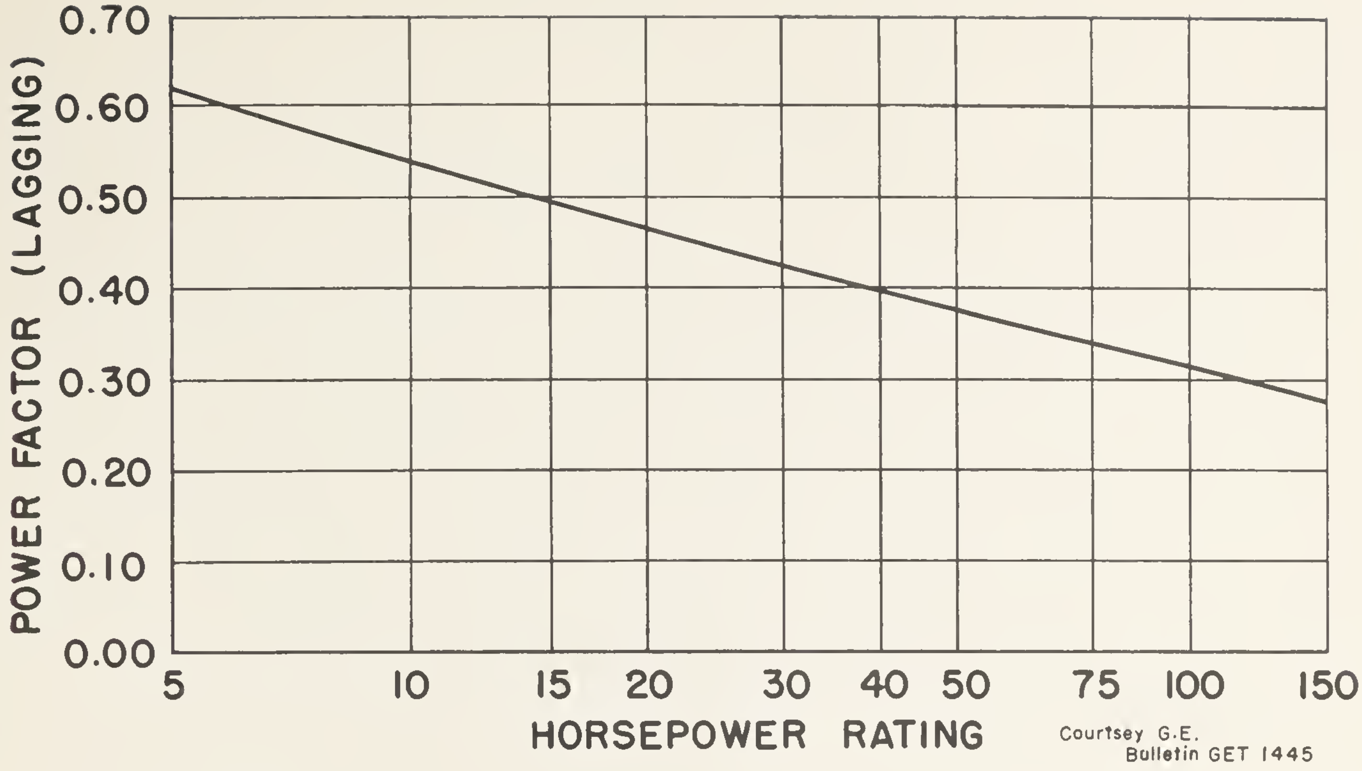

Fig. 5. Motor Starting Power Factors

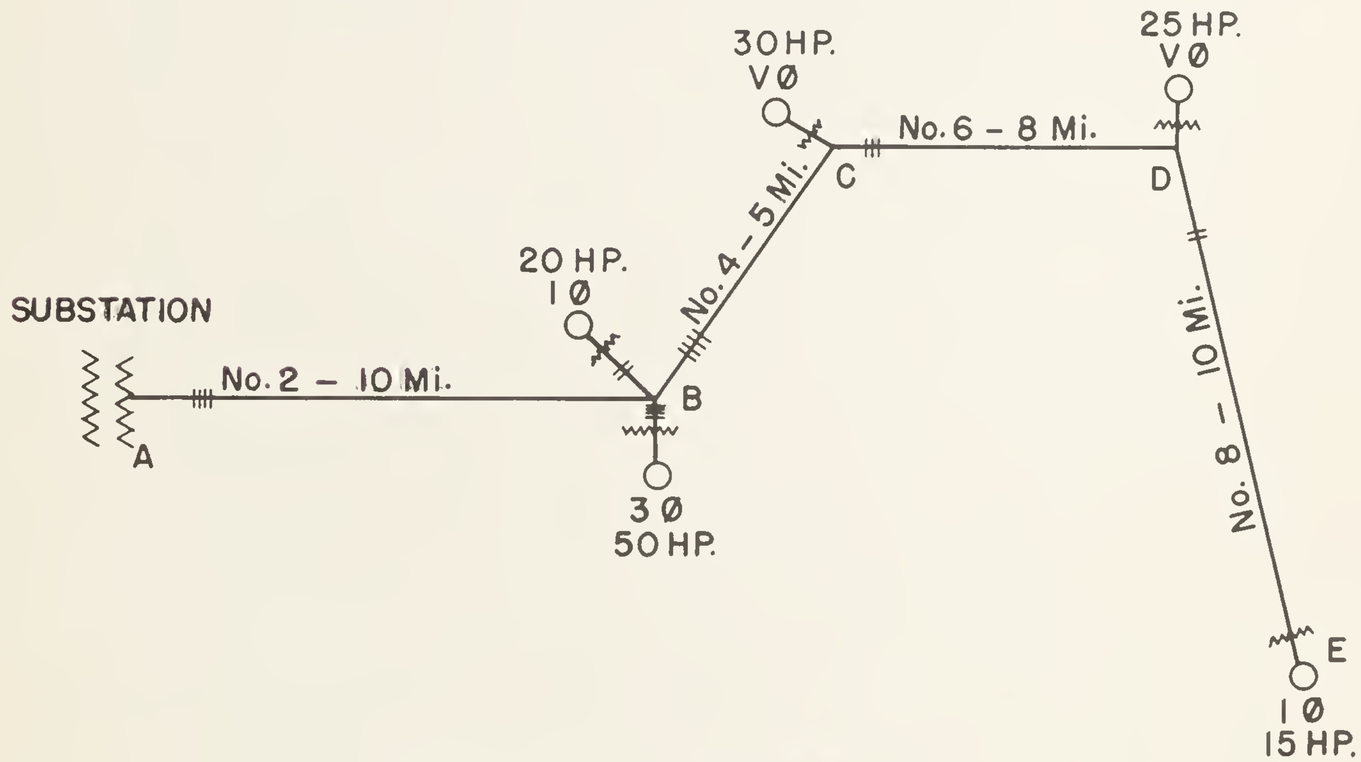

Fig. 6. Sample Problem

LOAD TRENDS ON RURAL LINES

AND

METHODS OF RECORDING AND CALCULATING DATA

By John E. Case
Field Engineer
Northeast Area

For Presentation at the 1956 Technical Conference
For REA Field Engineers, Saint Louis, Missouri
January 16 - 20, 1956.

REA

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To assure freedom for the development of ideas which may serve to improve the engineering of rural electric systems, the authors of papers and discussions have been encouraged to explore new ideas and new techniques and to prepare papers which reflect their own engineering judgment and experience. Such an approach may develop ideas which deviate from industry practices and REA policies and procedures presently in effect. It should be recognized, however, that REA policies and procedures as set forth in REA bulletins are still applicable unless changed in the light of the ideas and experience which may result from such papers or discussions.

R G Zook

R. G. Zook
Assistant Administrator

LOAD TRENDS ON RURAL LINES AND METHODS OF RECORDING AND CALCULATING DATA

John E. Case

During the last few years the electric utility industry has experienced a very rapid load growth. This remarkable increase is partially due to the urban expansion of many towns and cities throughout the country. In many places the urban areas extend from one metropolitan area to another, thereby increasing the load through the increased number of consumers. This type of consumer is most generally a heavier user of electricity mainly because of the lack of other utilities in the area such as gas and water. In addition, he will make greater use of electricity through the use of food storage equipment especially when he is some distance from available sources and finds that he can buy cheaper in quantity. In some areas there has also been an increase in the number of small farms, probably resulting from splitting up the larger farms for greater farm production.

There has been a great lack of good available farm labor which has promoted complete electrification of a great many farms throughout the country. On top of all this, the manufacturing industry has been putting out an ever increasing number of high consumption appliances that have been accepted and are being used by many electric consumers. There was a time when Monday was wash day. Now any day is wash day because it is possible, through the use of a high consumption appliance, to wash and dry the clothes in one operation every day in the week and yet not spend as much time as was required to do the Monday wash. Because of these and other conditions, a tremendous load growth has resulted. This load growth makes it necessary to install additional capacity in distribution systems and to take into consideration more complicated operating problems.

After analyzing all the data available on load growth, it is impossible to say when, in the future, this rapid increase will begin to taper off or tend to rise less rapidly. However, in the meantime, it is necessary to keep the system capacity abreast of, or just ahead of, this increase. The tool devised to take care of this situation is the system study. This system study is, more or less, a calculated estimate of what should be done to take care of certain loading conditions. These loading conditions are generally determined from past consumption records and a projection into the future of the trend of this consumption. Too often it is assumed that there will be no deviation from this trend. All calculations are based on set time periods, such as two, five and ten years, as indicated by this assumed trend. It is true that feeder loading can be calculated and an analysis made. However, in these calculations it has been necessary to make those assumptions which often have a tendency to distort the true picture. In many cases over-capitalization may result from the premature installation of large conductors because the recommendation was made for that time period and executed in that time period when the improvement was not actually needed for several more years. The fact that the actual situation has deviated from the assumed condition is not taken into consideration.

The only positive way to determine load is to actually measure it. Load measurements are relatively simple and easy to make and when properly made and recorded furnish a wealth of operating data that cannot be gained otherwise. Let us consider the value of some of these measurements.

PHASE LOAD BALANCE

It is possible to accurately determine the phase load balance on any substation, feeder or other source by taking current demand measurements at the point in question. In the case of the substation, a thermal current demand meter installed in the ground lead of each single phase transformer will indicate the current demand of that phase on that particular transformer. In the case of a feeder or other three phase source, current demand meters installed on the first pole from the source or station will indicate any unbalance that should be corrected. Now, by taking this same type of measurement further out the feeder, one can find a tap or combination of taps that will give the necessary amount of correction. If peaking meters are used, the maximum demand can be determined; however, if the time of the peak is desired it is necessary to use recording meters. All balancing should be done for the peak loading condition. Referring to Figure 1, we note that the unbalanced phase loading must be corrected. The indicated loading for the phases at the station are A-40 amps, B-72 amps and C-38 amps. The ideal balance would be 50 amps in each phase. This would require an addition of 10 amps on phase A, reduction of 22 amps on phase B, and addition of 12 amps on phase C. Now, by going further out on the feeder and making current demand measurements, we find that at point 2 on phase B we have a 10 amp demand. This tap can be transferred to phase A to complete the ideal balance on that phase. Going out on the feeder, at point 4 on phase B, we get an 8 amp demand, and at point 5, also on phase B, we get a 4 amp demand. By transferring these two taps to phase C we have increased phase A by 10 amps, decreased phase B by 22 amps, and increased phase C by 12 amps, thus accomplishing the ideal balance of all phases.

LOAD SHIFTING

When shifting load, either temporarily or permanently, it is necessary to know how much load is being shifted and what the result will be. Let us refer to Figure 2 to further explain the use of load measurements in load shifting operations. Because the load is considered to be the voltage times the current we have taken only current demand measurements at stations S-1, S-2 and S-3, and at Switch SW-3. Switches SW-1 and SW-2 are operated normally open. We can see that the stations are fairly well balanced. The full load current of the stations is 35 amps at S-1, 70 amps at S-2 and 104 amps at S-3 at 7.2 KV. Now let us explore the load shifting possibilities.

We will open SW-3 and the switches at S-1 and close SW-1. Immediately, we increase the demand on S-1 by the demand at SW-3. Then, the demand at S-1 becomes A-72 amps, B-72 amps and C-71 amps. This represents a 100 percent overload on S-1 and is not deemed good practice. In addition, we find that the No. 6 conductor from S-1 south is somewhat overloaded and therefore the regulation in the section from SW-3 to SW-2 will be excessive. Thus, we see that S-1 cannot carry this additional load.

Now let us close SW-1 and SW-2 and open SW-3. The switches at S-1 are also opened. Thus, the S-1 and S-2 systems are both fed from S-2. Immediately, the current demand becomes 92 amps at A, 91 amps at B and 90 amps at C at point S-2. Inasmuch as the full load current at S-2 is 70 amps, we see that the demand is excessive and cannot be held for long periods of time. However, for short periods S-2 is capable of holding 1.5 times normal capacity which would be 105 amps. Thus we see that S-2 can handle this condition for a short period. Also, the new demand does not overload the No. 2 conductor feeding from S-2, so there will be no regulation problem for this situation.

Now let us close SW-1 and open the switches at S-1. Immediately the demand at S-3 becomes 112 amps on A, 111 amps on B, 112 amps on C, and at SW-3 becomes 72 amps on A, 72 amps on B and 71 amps on C. Immediately we see that the No. 1/0 conductor between S-3 and SW-3 is not overloaded, so there will be no regulation problem in this section. Likewise, the demand at SW-3 will not overload the No. 2 conductor so the regulation in that section will be satisfactory. Investigation of short period feed shows that the demand is appreciably less than the overload capacity of 156 amps at S-3, so the load can be handled for short periods. Investigation shows that this load cannot be fed for long periods from S-3, as the demand exceeds full load current by 37.5 percent which results in an overload which is not desirable. It is imperative that the measurements at S-1, S-2, S-3 and SW-3 be made periodically and properly recorded, so that the latest data is available.

In periods of emergency when extensive switching operations must be carried out, it is necessary to know just how much load will be switched so that by-passes on sectionalizing equipment can be re-fused to handle the added demand. These operations must be carefully planned starting with measured current demands at the major switching points.

Too many times the system study will make recommendations for extensive improvements over a general period of time, such as the 1956-7 period. The statement will be made something like this -- "In the 1956-7 period, it will be necessary to carry out the following changes, etc." This statement is made assuming that the load trend will follow the trend indicated by the 2, 5 and 10 year consumption figures that the system study calculations are based on. No deviation from this trend has been taken into consideration. We know from experience that we run into these deviations every day and find that some section of the system is overbuilt or underbuilt. Either too much money has been spent overbuilding or extra money must be spent correcting an underbuilt condition. This happens because of the generality of the time specified to carry out system improvements. This time, however, can be pinpointed by using the data available from system-wide current demand measurements to show when the demand in a particular section approaches the allowable load limit of the circuit. It is an established fact that the regulation due to load becomes excessive as the demand approaches the loading limit of the circuit. Thus we see that there is a point, generally 80 to 90 percent of the loading limit, where the measured demand tells us it is time to start the recommended system improvement in the system study for this section of line. The percentage figure must be set up for each organization depending on the availability of materials and labor, physical characteristics of the job and the ability of the operating personnel to coordinate all efforts. If there is no recommendation for this section in the system study, it is evident that the time period must be started earlier to allow an engineer to properly study the condition and make recommendations for corrective measures.

One of the duties of every good operating man is to watch the regulation on his lines and to correct any such condition which arises before it becomes excessive. The overall voltage drop from the station to the farthest end of any phase can be measured very easily with recording voltmeters. If the regulation is excessive or more than seven percent at the peak load period, it is apparent that corrective measures, as recommended by the system study, should be taken immediately. If several areas of correction are indicated in the system study, then recording voltmeters can be set at both ends of those areas to determine whether the excessive drop occurs in a specific area or whether it is general over the length of the phase. Once again it is preferable that meters of one percent accuracy be used to make these measurements.

Getting down to the individual loads that add up to make the total load, we find that simple measurements will dictate the size of transformer to capably handle the demand on it. By using a two-meter trough in the present meter socket it is possible to leave installed the present kwh meter with which the member is familiar and also to install a thermal demand ammeter, calibrated in KVA to indicate the present and peak demand. Should the demand read high and the consumption low, it is apparent that the peak is a short erratic one. Inasmuch as most transformers can stand about 50 percent overload for short periods, it can be assumed that the capacity of the transformer, needed to handle this load, will be between 2/3 and 3/4 of the peak demand, whichever is closer to a standard size transformer. In cases where the consumption for the month is fairly high, the demand reading will dictate the size of transformer necessary to handle the load. In the case of very high consumption, the transformer should never be smaller than the peak demand reading in KVA. By way of illustration let us say a 5 KVA demand and a 120 kwh consumption indicates the need for a 3 KVA transformer. Further, a 5.8 KVA demand and 600 kwh consumption indicates the need for a 5 KVA transformer. Then a 12 KVA demand and 2300 kwh consumption indicates the need for a 15 KVA transformer. This method does not allow too much room for expansion or added load, and in most cases should be increased one standard size to take care of any additions.

Any measurement that is important enough to be made is useful and should be preserved until its usefulness is at an end. All of the measurements that we have discussed should be made a matter of record. The measurements should be taken at regular intervals and at specified locations. After a series of tabulations it is possible to set up curves and charts that will indicate the actual trend in load increase for any location or for entire feeders and areas.

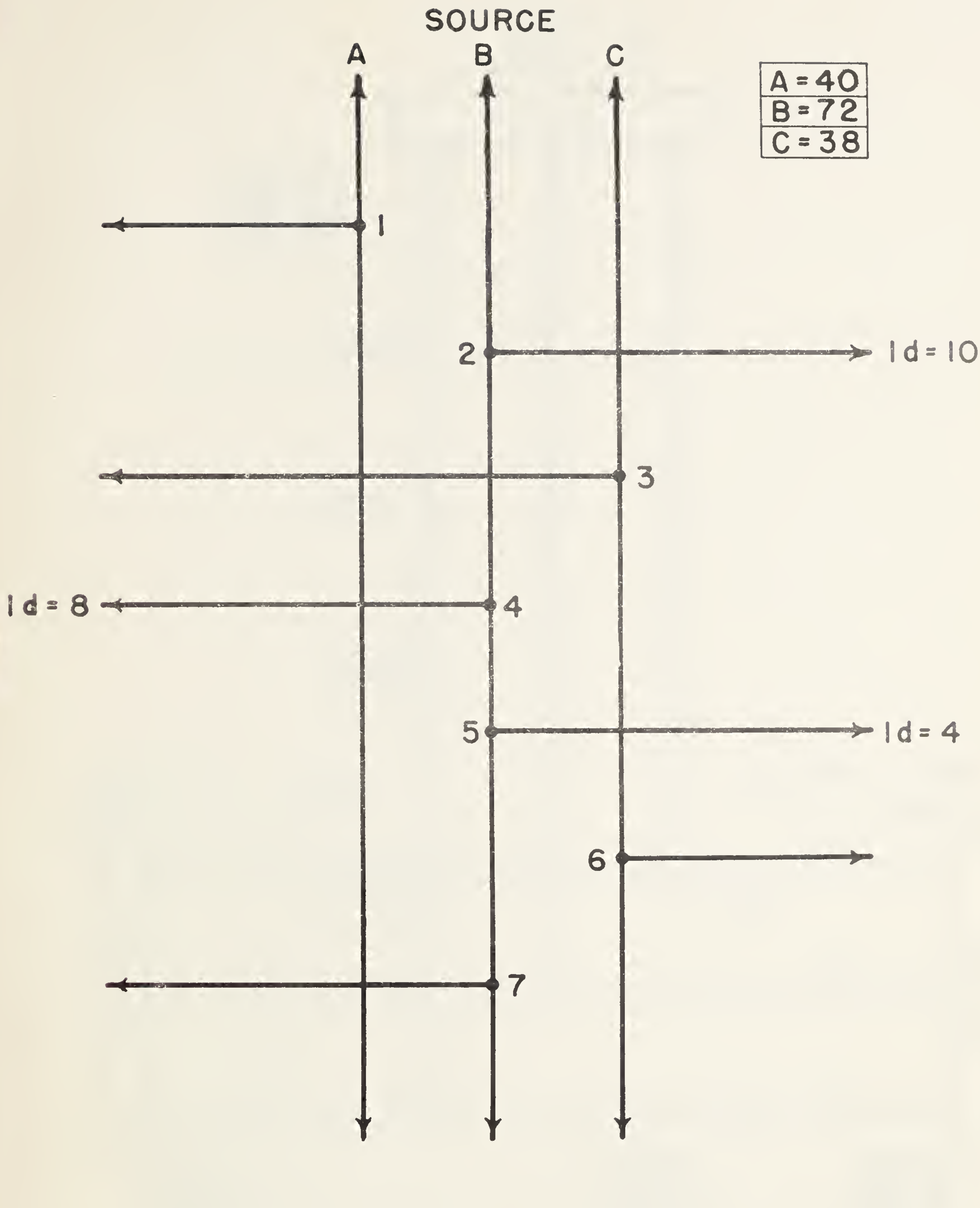

Fig. 1. Phase Load Balance Diagram.

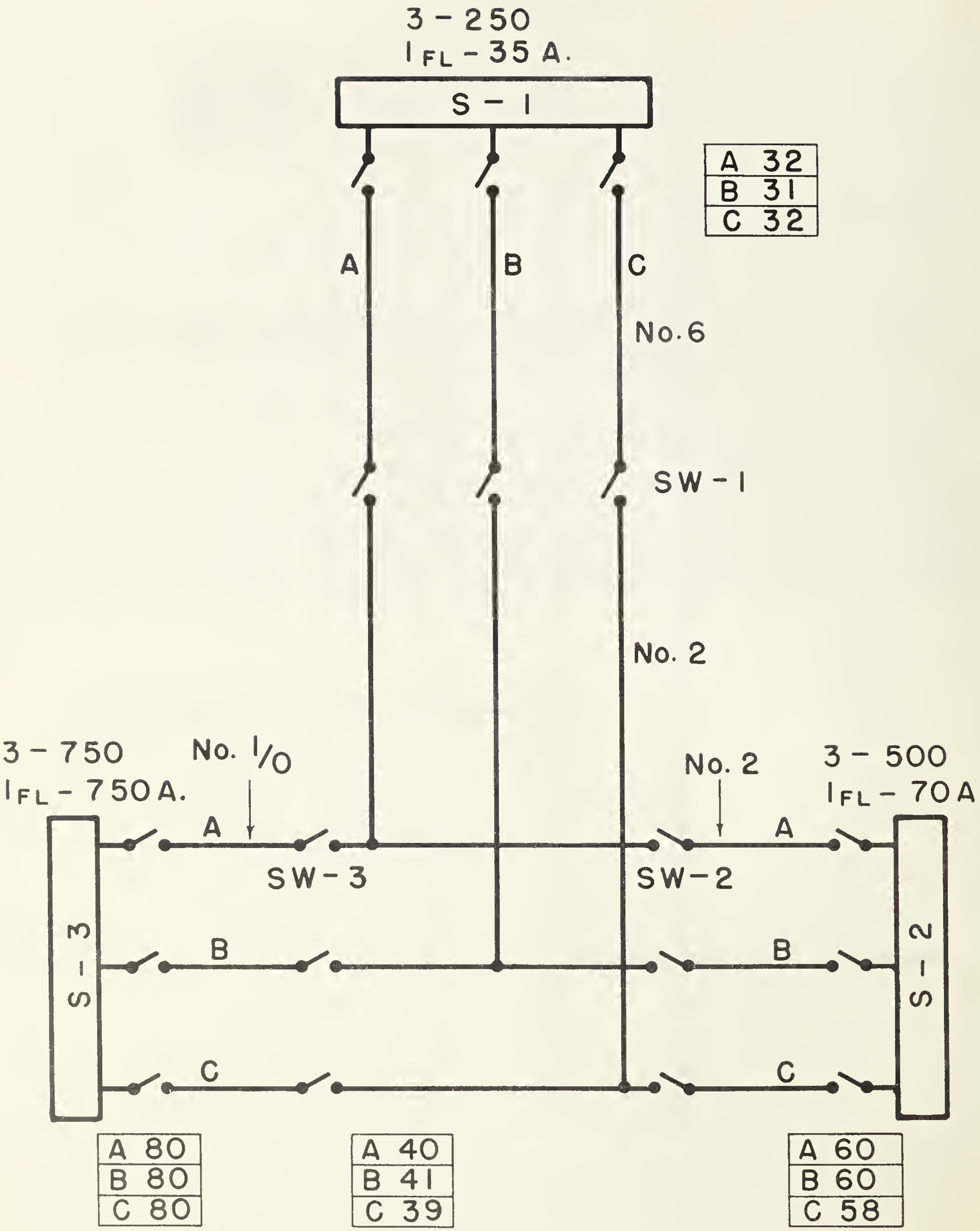

Fig. 2. Load Shifting Circuit Diagram.

SYSTEM IMPROVEMENT PLANNING

By W. J. Hauck
Field Engineer
Western Area

For Presentation at the 1956 Technical Conference
For REA Field Engineers, Saint Louis, Missouri
January 16 - 20, 1956.

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R G Zook

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Assistant Administrator

SYSTEM IMPROVEMENT PLANNING

W. J. Hauck

INTRODUCTION

System improvement planning needs to be improved!

System improvement planning of REA financed systems is normally based on system studies. Currently, such studies are expected to be correlated with two, five and ten year projections of power requirements. Too often, however, the present experience is that the load has grown faster than was anticipated and the system study is outmoded before the ten years have passed. System study procedures should be enlarged to include an overall plan for the system when the load reaches saturation. Saturation should be considered at a minimum of 3,000 kwh per month per farm and non-farm users. Large power loads, commercial loads, etc. should be considered separately.

System improvements should then be made as the load grows instead of being based on a two, five or ten year plan. Planning for construction should be only two to three years in advance. The express purpose of this paper is to help prevent unnecessary costs and avoid improper design. Thus the making of expensive system improvements before the load requires them is contrary to intention.

It is anticipated that the overall plans of some of the systems will need to be revised because of unforeseen load trends. In fact, periodic review of the overall plan and comparison to the load growth is tantamount to having an overall plan. The overall plan enables the engineer to determine earlier, than under the present procedures, whether the most economical system improvements are accomplished by use of:

1. tie lines and multiphasing
2. larger conductors
3. higher distribution voltages
4. more supply points
5. sub-transmission lines
6. regulators and capacitors
7. combinations of the above

Thereafter the planning and resulting construction can always be toward a goal. The borrower will be able to ask himself "Will this improvement permit expansion of the system economically or will it become obsolete and have to be replaced?"

GENERAL

In the past there has been a question of how many kwh per month the rural consumer will require when his electrical use reaches saturation. Now, however, enough information is at hand to make a fairly reasonable prediction. Saturation will be reached when he is using electricity for all the conveniences that he wants and for such necessities where electricity is more economical than other types of fuel or energy. It may sound unrealistic but very often cost is secondary to convenience. Space heating is definitely included - in time even at higher costs. In those areas where low wholesale rates have encouraged earlier use of electricity for house heating it is found that the average consumer (having electric heating

and other major electrical appliances) uses around 3,000 kwh per month. Some use considerably more. However, at this time 3,000 kwh appears to be a reasonable overall average. The lack of space heating in the past should not be considered as an indication of what may be expected in the future. Space heating has not been encouraged because of limited power supplies and distribution facilities. In many cases it was even strenuously discouraged. Other uses of electricity however, both within the home and elsewhere, have increased. Thus, generation, transmission and distribution facilities must be increased anyway and space heating is being viewed with less alarm. Where space heating has been encouraged the response has been very satisfying. Equipment suppliers are beginning to push electric heating whereas previously they were reluctant to do so. As the advantages of heating electrically become better known the swing to it will be accelerated. Air conditioning has become popular in many areas. The counterpart of air conditioning is space heating.

If the advent of space heating is not given consideration there will be danger of uneconomical planning of systems. In some areas it may be true that space heating will not make much inroad during the next ten years. But what about the period immediately thereafter? It is possible to design a system and plan improvements that will handle the predicted ten-year load, but cannot be expanded economically to handle any greater load. Further, the effectiveness of the system design may be so short-lived that the cost of the improvement will be greater than the benefits derived. For example, one borrower has been gradually, but methodically, reinsulating its 1,400 miles of 7.2/12.5 kv lines for 14.4/24.9 kv. The plan was to convert to the higher voltage when the increasing load brings about excessive voltage drop. Their next step would be to change the existing conductor to a larger size. But when the load still continues to grow the only relief would be through additional supply points, probably involving construction of transmission lines. Now, if it is known at the outset that additional supply points will be needed it may be more economical to add them sooner and stay with 7.2/12.5 kv in some or all of the areas. It should be remembered that conversion from one voltage to another involves considerable service interruption and a great outlay of money for the transformers of the new voltage.

This borrower made a rough analysis of the design requirements for serving an average of 3,000 kwh, per month per farm and non-farm consumer and found that some of the reinsulated lines should remain at 7.2/12.5 kv. It was also found that in parts of the system the higher voltage would not be adequate without additional supply points. As a result of this analysis the borrower found that the addition of some transmission line and new supply points, at the existing voltage, will bring about better design, will cost less and can be accomplished with a minimum of service interruption.

Experience indicates that on the average rural distribution system the use of conductor larger than No. 2 conductivity is less economical than alternative improvements. Experience further indicates that in many cases No. 2 conductivity, on the trunk lines and at 7.2/12.5 kv, is only adequate up to about 500 kwh per consumer per month. Many systems are just reaching this critical load point. They are the ones that stand to gain the greatest economy by looking ahead. If they look no further ahead than ten years the power requirements for the tenth year will probably not be predicted above 1,000 kwh per consumer per month. In many cases it will be found that a load of this proportion can be served satisfactorily by converting some, if not all, of the system to 14.4/24.9 kv. But theoretically, this

voltage can handle only about four times the load of 7.2/12.5 kv. Thus the system that could handle 500 kwh at 7.2/12.5 kv could only handle 2,000 kwh at 14.4/24.9 kv. It should be remembered that the increased capacity applies only to that portion of the system that is changed over. After the load grows beyond the 2,000 kwh additional substations and transmission lines may be the only remedy. Now it may be that this load could be adequately served at 7.2/12.5 kv with the same number of substations. Consequently, changes to 14.4/24.9 kv should be made only after full consideration has been given to the load increase and resulting system improvements, beyond the tenth year.

The consumption curves of REA borrowers illustrate that a rapid load growth must be anticipated. Figure 1 is the curve of the above mentioned borrower. It is found that while the curve is parabolic in appearance it is not a true parabola. The formula for the last five years, $Y = (.115\ x + 4.5)^2$ shows that the load is increasing at a faster rate than during the first few years where the formula was $Y = (.07\ x + 6.7)^2$. It is entirely reasonable to assume that this curve is undergoing constant acceleration. If space heating is pushed the curve will undergo a sudden upswing. However, even without acceleration, this curve indicates that the load will reach an average of 3,000 kwh by 1977. The curve represents only the mean of the monthly averages. There is considerable variation between monthly averages and hence for some months the average may reach the 3,000 kwh limit long before the time indicated by the curve.

The pronounced variation of monthly averages is well illustrated in Figures 3, 4 and 5. The curve of Figure 1 is super-imposed on Figure 3. The same curve has been adapted to Figure 4, but the whole curve has been moved upward by 300 kwh. In Figure 5 the same curve has been adapted in two ways; once by moving upward by 400 kwh; and once by advancing it to the left by six years. A third curve (a straight line) has been added for comparative purposes. For statistical purposes the straight line curve appears more applicable than the other two. However, the consumptions of 1,097 kwh in January 1950, 1,155 kwh in January 1952 and 1,405 kwh in October 1954 make a design curve with a sharper incline advisable.

Figure 2 and Figure 6 are curves for borrowers with higher power rates. Figure 2 was plotted from average annual figures and consequently the monthly fluctuations are now shown. Until recently the borrower represented in Figure 6 suffered from:

1. frequent and extended service outages
2. poor voltage regulation, and
3. lack of power use activity

Some transmission lines and substations were added recently. A new manager has been employed who is determined to eliminate the long outages. He also will inaugurate a power use program. This will result in a rapid upswing of consumption. It is to be noted, however, that the curve of these two borrowers, $Y = (.075\ x + 5)^2$ does not differ much from the lower end of the curve in Figure 1. From this can it be deduced that the present trends in low power cost areas is a forecast of what may be expected elsewhere. It should be remembered that high costs will no more deter the use of electricity than they do the purchase of new automobiles. The farmer will continue to increase his use of electricity. The concerted effort on power use will accelerate the increase. When the load increase is that obvious it should be planned for. It is entirely proper to plan more than ten years in the future. After all, it is proper that system planning at least covers the same length of time as the loan payments.

CONCLUSIONS

System studies should include a rough study of the "saturated" system. That saturated system should be based on at least 3,000 kwh per month per farm and nonfarm consumer. If some other known fuel within the system area, such as natural gas, makes electrical space heating unlikely, the 3,000 kwh should be adjusted accordingly. Wood, coal and oil, however, should not be considered as fuels that will continue to retard electric space heating. After the saturated system is determined the system improvements should be coordinated with the load growth. Then no harm will be done if the load growth reaches the projected ten-year average in less than ten years.

System improvements should then be planned so that there will be a minimum of changeouts. Instead, each step should be an addition. Thus, it is assured that each addition will pay for itself during its useful life. Compared to the current procedures such planning should result in considerable savings to REA borrowers.

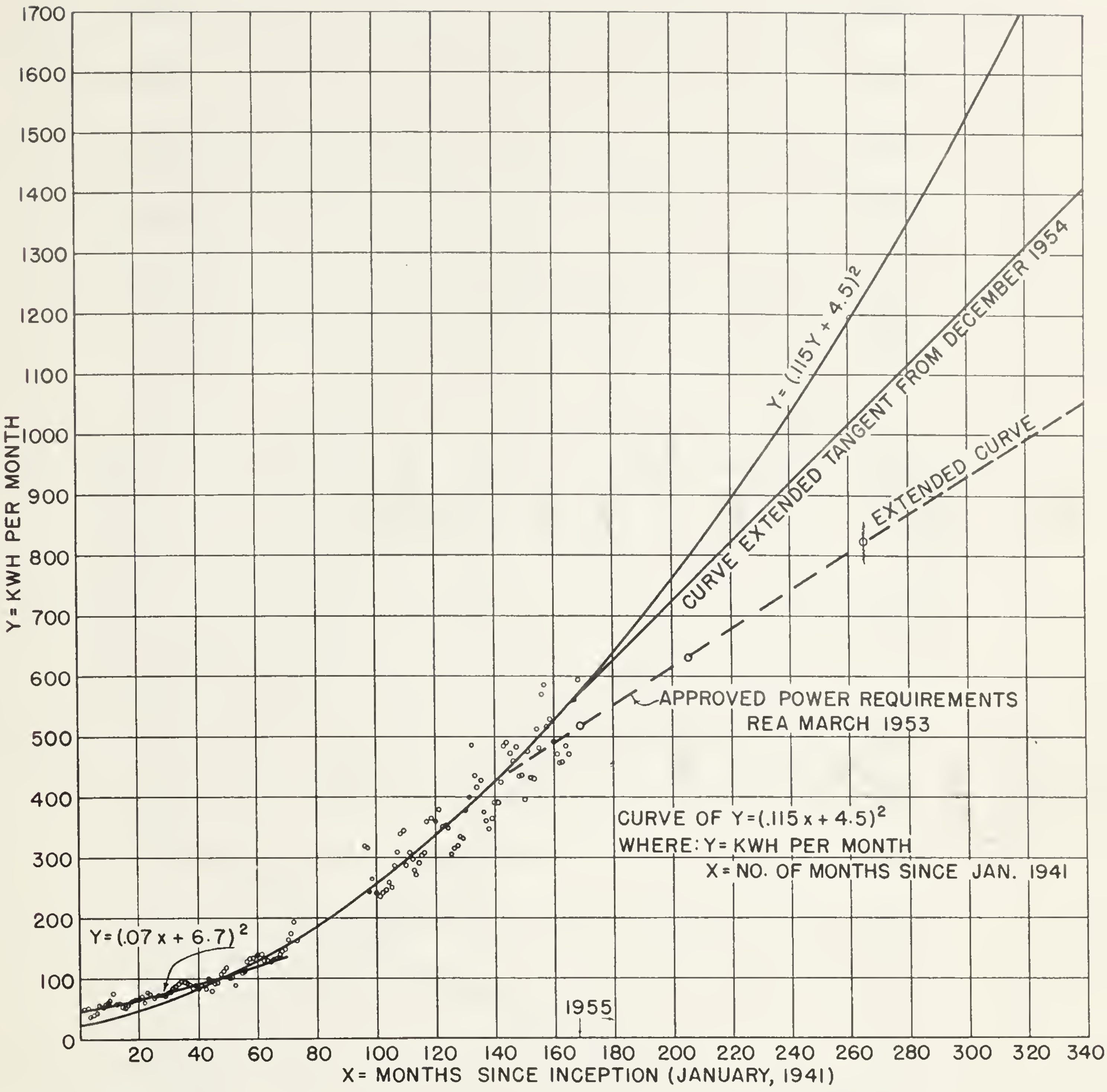

Fig. 1. Typical consumption curve used for deriving formula.

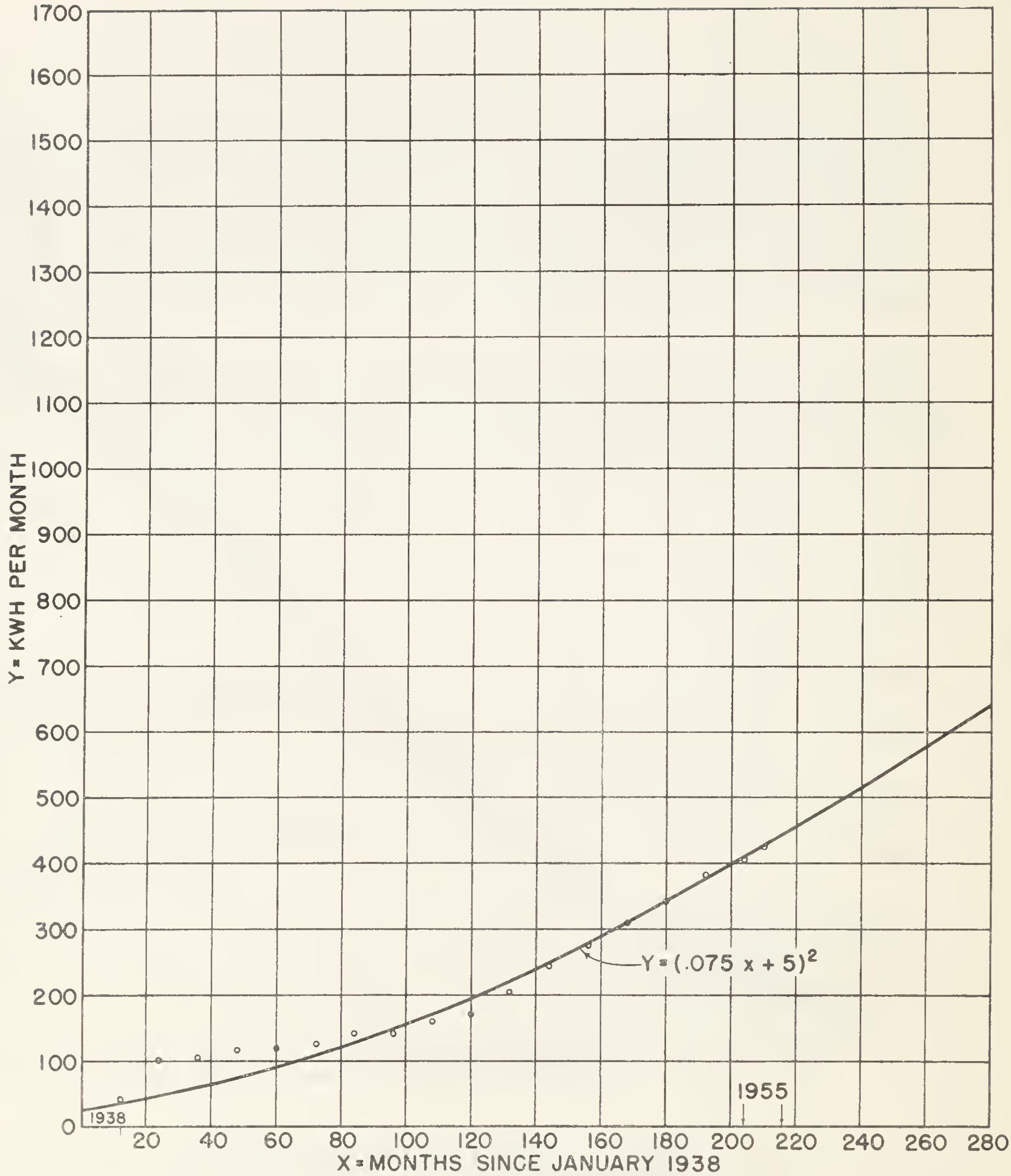

Fig. 2. Consumption curve based on annual averages only.

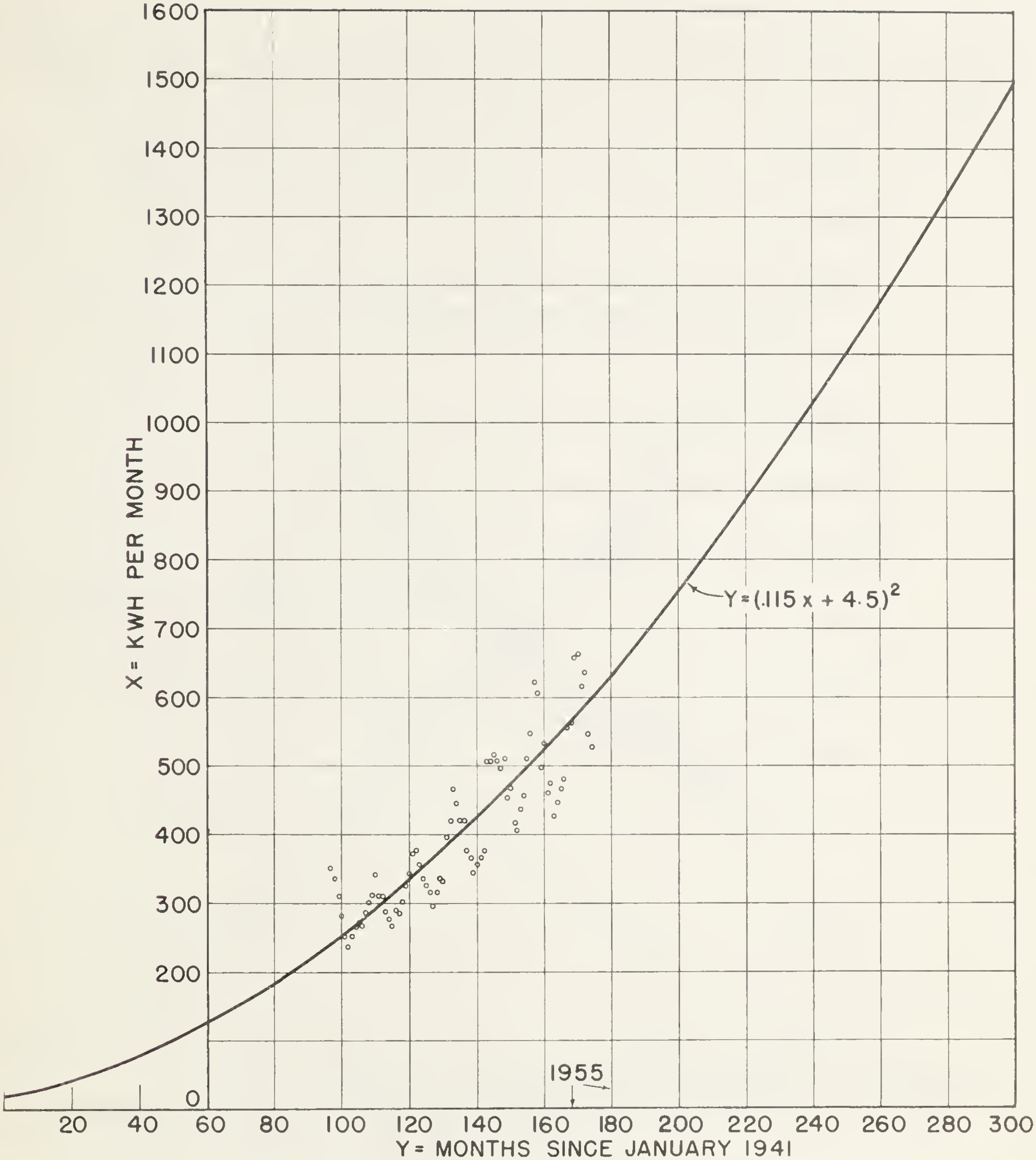

Fig. 3. Typical curve applied directly
to another borrower.

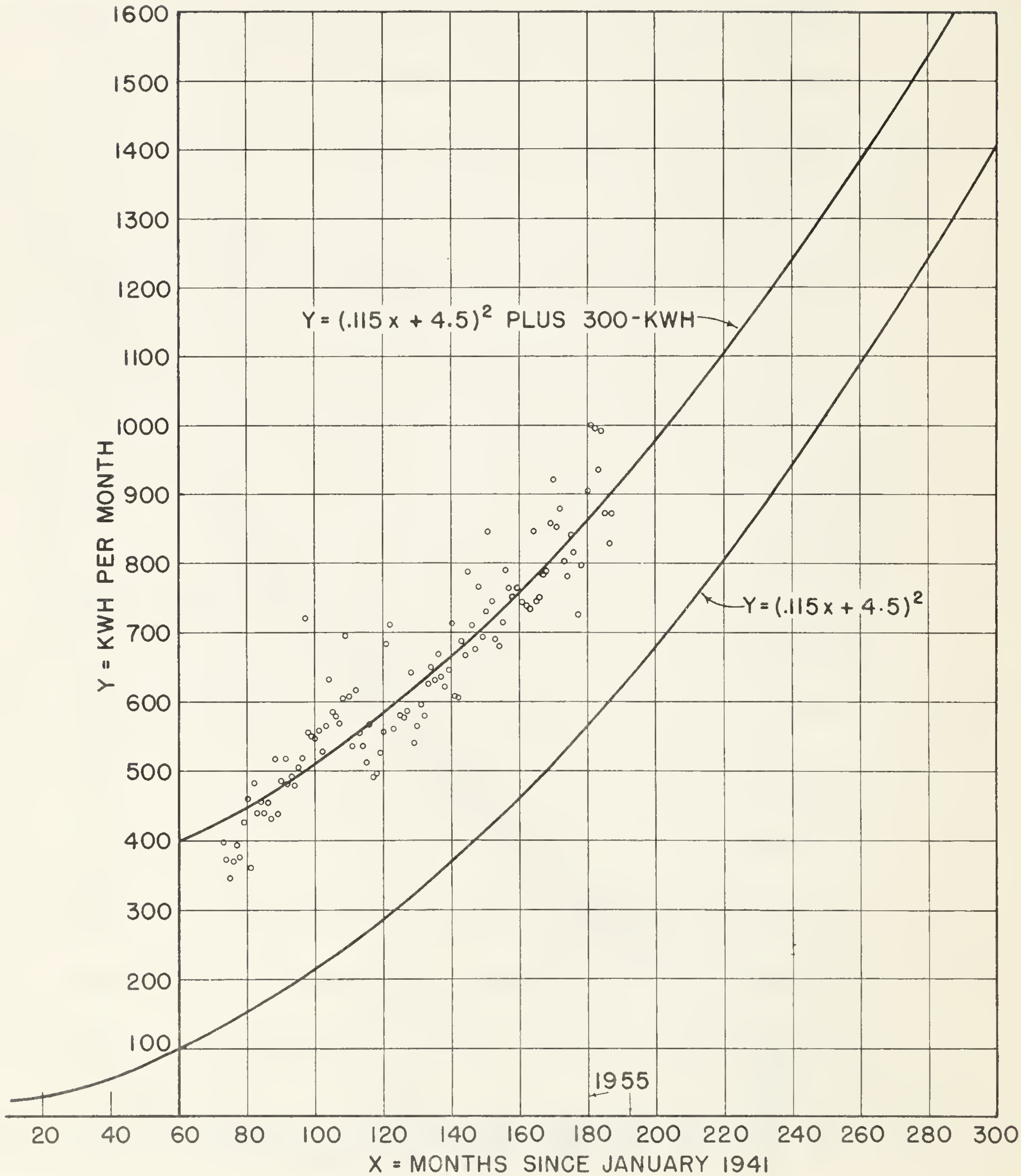

Fig. 4. Typical curve applied to borrower with high consumption.

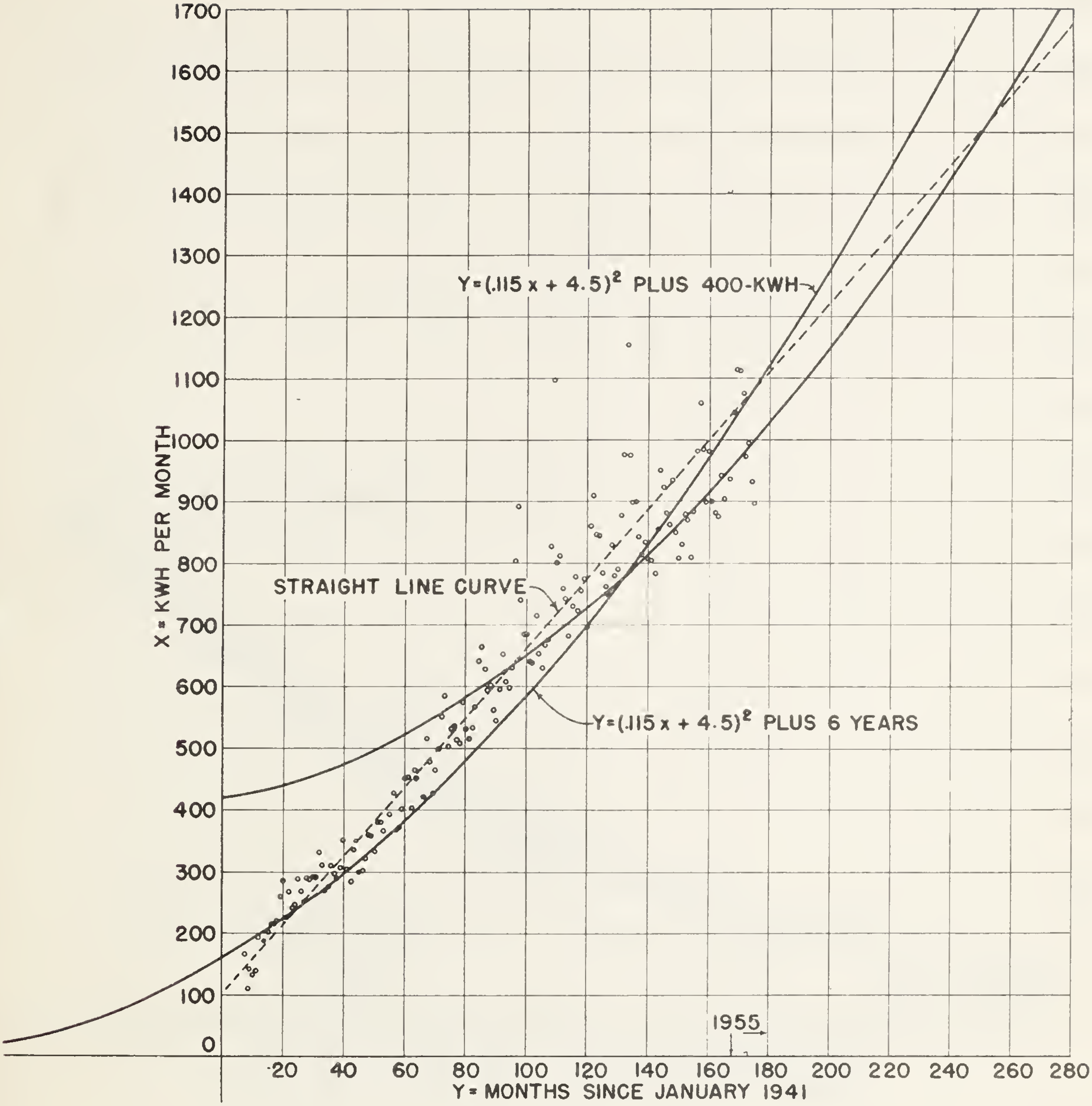

Fig. 5. Borrower with exceptionally high consumption. Typical curve is still applicable for planning.

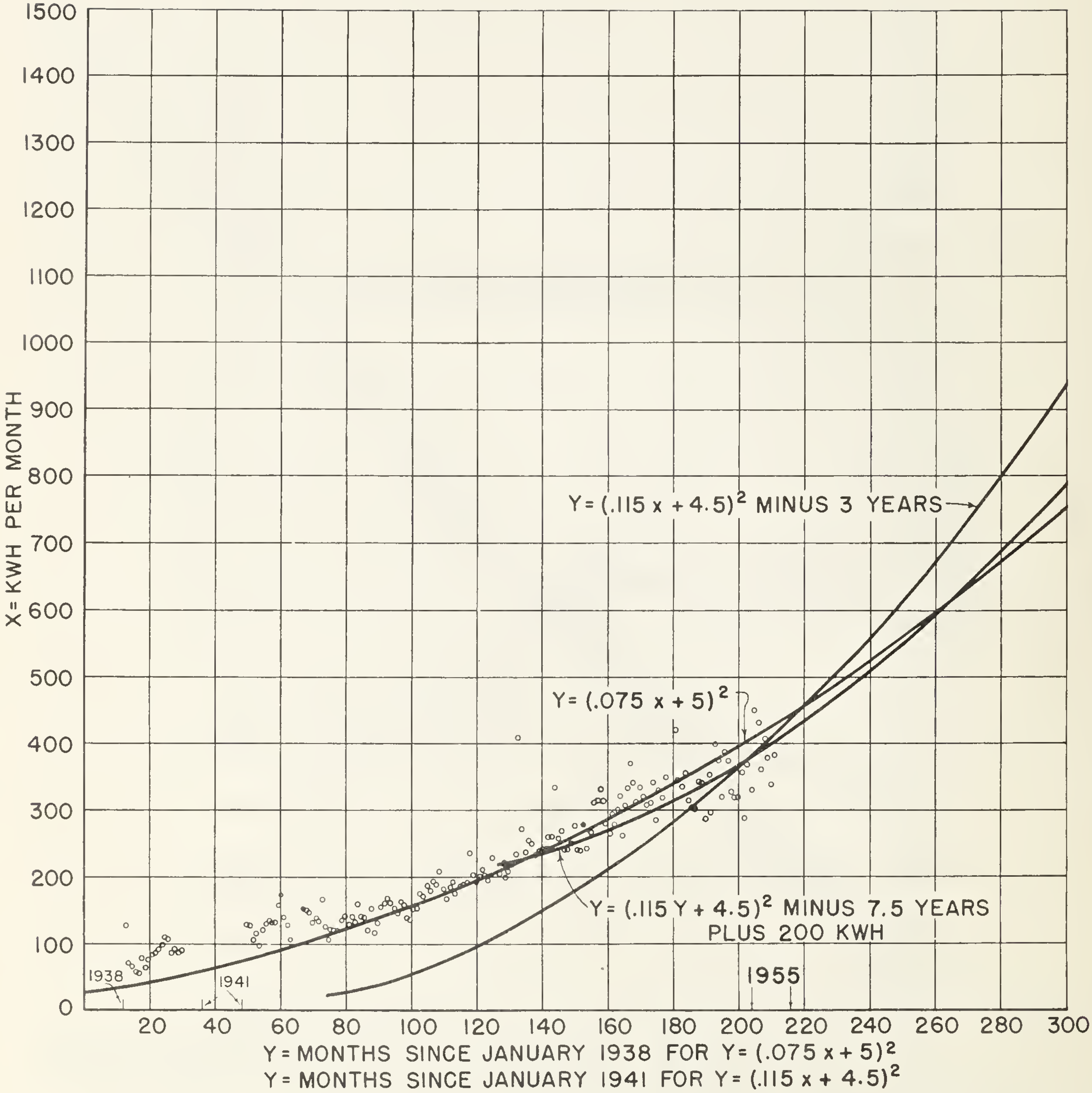

Fig. 6. Typical curve applied to borrower with low consumption.

THE KEARNEY HIGH POWER TEST SUBSTATION

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For Presentation at the 1956 Technical Conference for
REA Field Engineers, Saint Louis, Missouri
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U. S. DEPARTMENT OF AGRICULTURE

RURAL ELECTRIFICATION ADMINISTRATION

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RGZook

R. G. Zook
Assistant Administrator

THE KEARNEY HIGH POWER TEST SUBSTATION

W. W. Olive, Jr.

This afternoon, you are cordially invited to visit the Kearney Test Substation. In order that you may fully comprehend the function and make-up of the station, we would like to show you a movie that condenses three years of typical testing into 25 minutes of film time.

Our station was completed in October of 1952. It took a year of planning - a year to build - and about a 1/4 of a million dollars.

The station will look quite different to you than most substations with which you are familiar. In the first place, it is all wood. We constructed it at a time when steel was hard to procure. The copper busses are huge - 4" x 4" x 1/2 thick. Again, it was a matter of taking advantage of what was available rather than what was preferred.

Our test site is located in St. Louis County, along side of a Union Electric line connecting the Watson and Webster Substations. We energize our substation from a 34.5 kv line that provides back-up power totaling 445,000 kva.

The 34.5 kv incoming line energizes a 10,000 kva transformer which has 4 secondary taps of 15, 7.5, 5, and 2.5 kv. The maximum calculated fault that we can obtain is 10,000 amperes at 15 kv, 20,000 amperes at 7.5 kv, 20,000 amperes at 5 kv and 40,000 amperes at 2.5 kv.

The output from the 10,000 kva transformer is led into a motor operated disconnect switch, then thru a 250 MVA Oil Circuit Breaker and over to a bank of air core reactors. From the reactors, we connect to the test specimen and then to the ground circuit.

The 10,000 kva transformer is designed for intermittent duty, but it has radiating fins that allow us to keep it energized throughout an eight hour day.

All of our switching is done on the low voltage side of the transformer to prevent switching surges from causing repeated voltage dips on the Union Electric power line.

To prevent any outage on the power line, we go thru a very careful coordination check for every value of current at which we test and every size fuse that is subjected to that current. Every test specimen is backed-up by a second fuse switch that is hung on the same cross-arm and connected in series with the test specimen. The back-up switch is coordinated to clear in the event the test specimen fails and it must clear before the back-up oil circuit breaker is tripped by the COH relay. If the fault is long enough in duration, the breaker must clear before the power fuses blow on the 34.5 kv side of the station. The power fuses in turn must clear before the relay trip value on the Union Electric line.

All of our testing is performed in accordance with NEMA Standards. Our power factor is most always 20%. We obtain this power factor by combining five air core reactors in various combinations of series or parallel or both and then adding resistance to the circuit to give us an X/R of 4.9 and an impedance of appropriate

value to give the desired current.

In addition to our high voltage transformer, we have a 167 kva, 7.5 kv/120-240 volt transformer that allows us to obtain up to 26,000 amperes for testing disconnect switches for the NEMA momentary and four second ratings.

Our current measuring instruments are placed in the ground circuit between the test specimen and the transformer. The current trace is recorded by a direct writing oscillograph made by the Brush Development Co. In the event that records are needed for time values less than 1/2 cycle, we have available a cathode ray oscilloscope and a magnetic type oscillograph.

Safety devices and interlocks play a big role in the operation of our substation. Before a piece of equipment is tested, all personnel must go into the control house where they can observe the action through 1" bullet proof glass. This house is located about 50 feet from the test bay area. The door to the house has an interlock on it that will open the switches in the event that someone leaves the building before the "all clear" command is given. The test bay area has a large grounding switch that is closed before anyone goes into the area. Thus in the event that someone operates a control switch while a man is in the area, the grounded circuit will by-pass the test bay and automatically open the oil circuit breaker. When the last person leaves the test bay, the grounding switch is pulled open and the test is started when all men are accounted for inside the house.

In the way of camera equipment, we have a 16 mm B/H movie camera, a polaroid camera, and a "Fastax" high speed movie camera. We consider the camera to be a highly useful tool in our type of work. Sometimes they are as important to us as the oscillograph. Here's the reason for this. Our job is not only to find out how much a certain piece of equipment can be rated, but instead, how much is required to cause it to fail and more important, how and why does it fail. Armed with this information, it is then impossible for our engineers to pursue the proper way to make an item perform more efficiently and be built more economically.

To determine the "how" and the "why" of equipment failure, we must use the camera to supplement the human eye. Thus, we can get as close to the explosion as we need to, thanks to the close-up lens of the camera. We can stop the action during the peak of arc expulsion and study the arc pattern one minute after the test, thanks to the polaroid camera. Here is something else that one of our cameras can do for us. It will magnify the viewing time of mechanical motion 300 to 1. Thus, a mechanism that takes 1 second to operate can be slowed down on the movie screen so that it takes 300 seconds or five minutes for the identical action to be duplicated and viewed. The camera that does this job is our "Fastax" High Speed movie camera.

In our film today, you are going to see about a half dozen of the high speed shots. We hope that you are going to be greatly surprised at what you see. To make these shots, we operated our camera at 4800 pictures per second. Each picture requires the use of a 100 foot roll of black and white movie film. The one hundred foot roll of film goes thru the camera in 1 1/4 seconds. Once the camera is started, it cannot be stopped until the 100 foot roll is expended. Thus, only one picture can be made on a roll of film at the expensive rate of approximately $7.00 a second.

To gain this terrific speed in movie film travel through a camera, something

must be sacrificed, and that is light sensitivity. It is only possible to make high speed movies when there is intense light, such as that obtained from about four high powered spot lights placed several inches away from the subject. Naturally, we can't place spot lights that near to something that has 15,000 volts across it, and especially something that is vulnerable to releasing a cloud of ionized gas.

Our solution to the problem of obtaining adequate light from a safe distance is in the technique of using mirrors to direct the sun's rays to the test specimen. We also use a special film which has a speed index of 160. Under the best lighting conditions, we still get dark pictures prior to and following the expulsion of the hot luminous gases from the cutout. During the time that the gases are expelled from the cutout, the light is tremendously bright. In fact, the light appears in pulsations of brilliance that varies with the size of the billowing gases. Each billow of gas, or white "puff" as we call them, is a half cycle in duration. As the voltage wave goes thru zero, the light intensity decreases. As the envelope of the wave goes thru its peak, the light intensity increases. Thus, by counting the "puffs" we are actually counting half cycles and thereby we are counting the arcing time.

When presenting a movie such as the one we have today, it is very easy to bore the audience with a repetition of action. We have tried to avoid this by including as many different phases of testing at the substation as we possibly could. We have also selected from our film those shots that are the most spectacular; namely, equipment explosions. Also, included in the film are two sequences showing the step by step development of two new trip-outs.

After the film, I will try to answer any questions you may have. Following this, we will adjourn and take a trip out to the substation where you will witness a few tests. We hope that you will enjoy our movie.

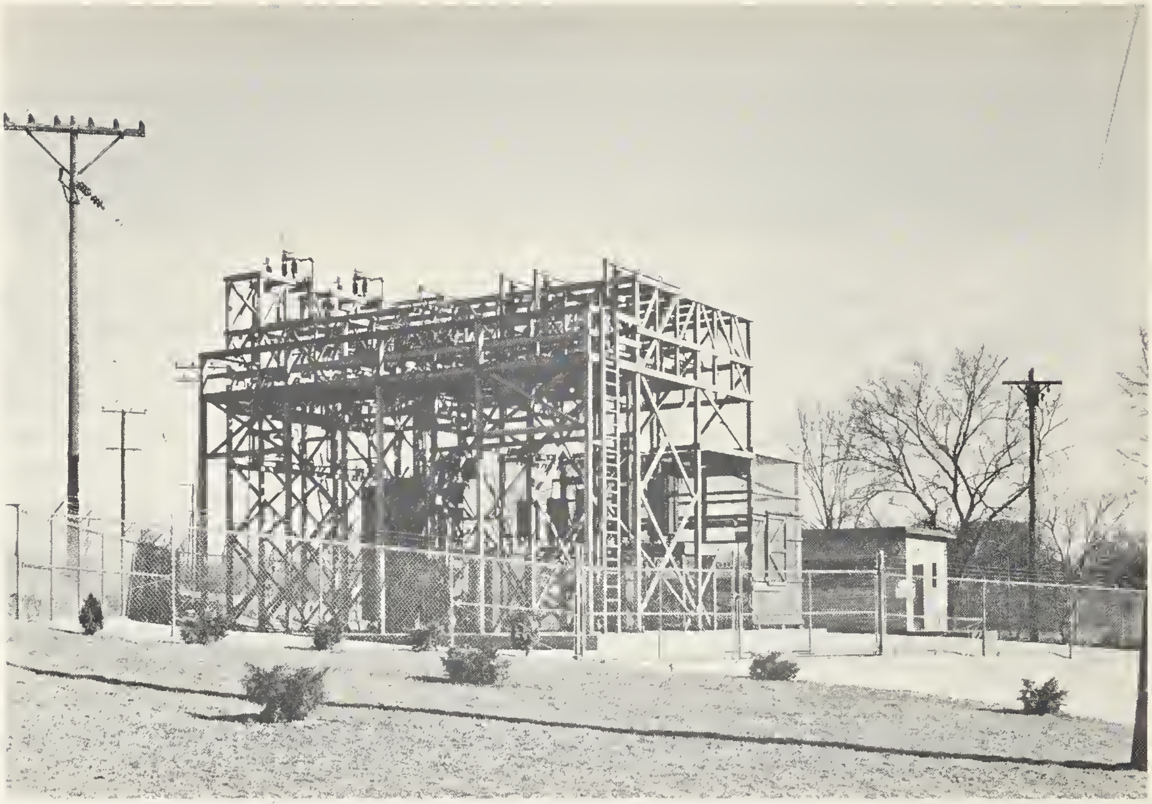

Fig. 1. Kearney Outdoor Substation--Rear View. Structure is made of laminated wood treated with penta preservative.

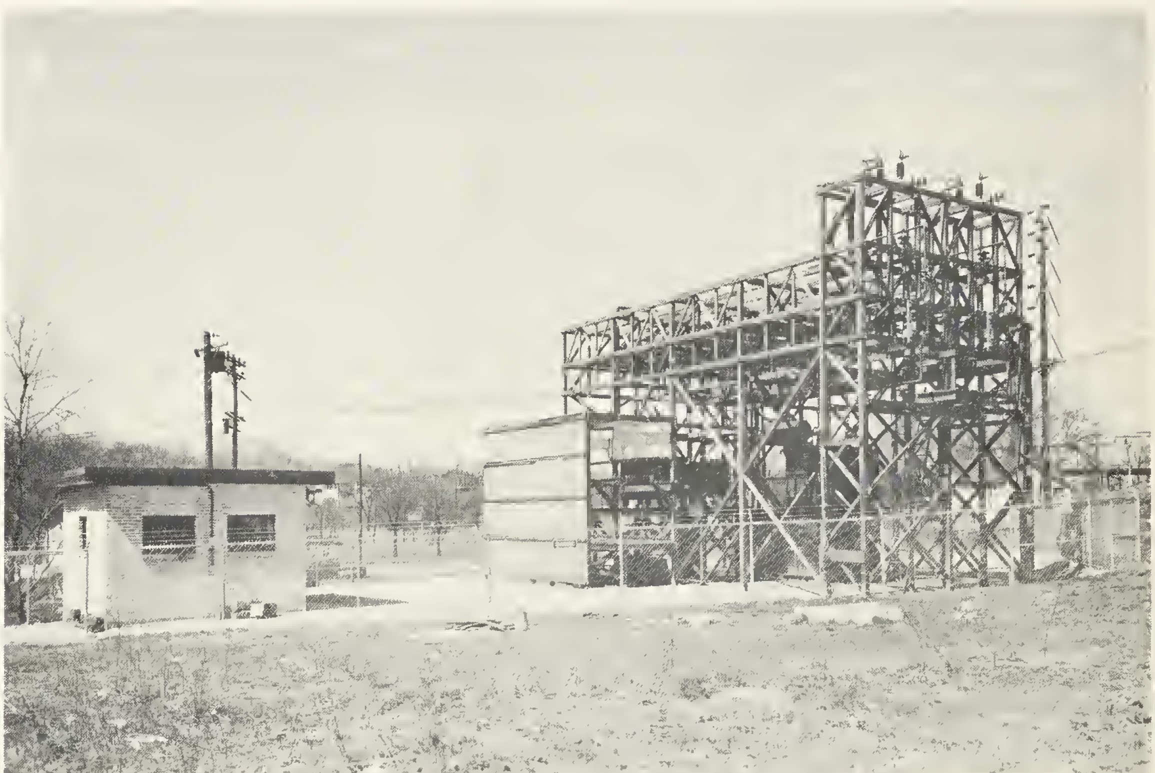

Fig. 2. Kearney Outdoor Substation--Front View. Connection to Union Electric Company's 34.5 kv line is shown at upper right.

Fig. 3. Kearney Type G Heavy Duty Trip Out Cutout, 100 amp, 7,800 volts, No. HDG-781, Interrupting 5,000 amp, 7.69 kv, 20% pf. Picture taken with Polaroid Camera.

A SHORT SUMMARY OF THE

PROBLEMS OF NUCLEAR POWER

By William C. Morris
Electrical Engineer
Electric Engineering Division

For Presentation at the 1956 Technical Conference for
REA Field Engineers, Saint Louis, Missouri
January 16 - 20, 1956

REA

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A SHORT SUMMARY OF THE PROBLEMS OF NUCLEAR POWER

William C. Morris

Atomic or more properly nuclear power has been receiving worldwide attention. Probably no technical development in history has been the subject of so much publicity. This intense interest is compounded of awe of the bombs and a realization of the tremendous potential possibilities if this new energy source is harnessed for the good of man.

It should be remembered that this great potential is not going to be realized without a lot of hard work combined with liberal doses of imagination.

The fission of uranium was first observed in 1939. In the 16 years that have elapsed since then great progress has been made, especially when it is measured alongside of the 150 years or so of steam power and about 75 years of the electric power industry.

The cause of all of this interest is the fact that when one atom of uranium fissions it liberates about 200 million electron volts (MEV) of energy, mostly in the form of kinetic energy which immediately is converted into heat. 200 MEV is a very small amount of energy but there are 6.0×10^{23} atoms per gram atom. In the case of U235 there are 235 grams per gram atom. In other more familiar units, if 1 pound of uranium is completely fissioned 11,400,000 kwh of heat energy would be released. This compares with the 3 or 4 kwh of heat from the combustion of 1 pound of coal. This means in effect that fissionable material would provide a weightless fuel.

Everyone in the electric utility business is well aware of the increasing demands for power which is reflected as a drain on the world's supply of fossil fuels. It has been estimated that the world's reserves of all fossil fuels total 80×10^{18} BTU; uranium and thorium supplies are estimated to total 1800×10^{18} BTU. It may not be too long, perhaps not in our lifetime, but certainly sometime in the future we may be forced to rely on fissionable materials as our major energy source. The British see this problem as a pressing one because of the difficulties they are having with their coal supply.

The application of nuclear energy by the electric utility industry for every day use is not going to be easy, but let us examine some of the problems it entails.

The key to the release of nuclear energy is the neutron, a very small particle weighing 1.67×10^{-24} grams which has no electrical charge. This lack of electrical charge makes the neutron extremely effective in initiating nuclear reactions. It can enter the nucleus without having to overcome the electrostatic forces surrounding it. The neutron does not, however, cause the desired nuclear reaction under all circumstances. The conditions must be just right. Getting the right conditions is complicated by the fact that we cannot control the movements of the neutron. Conditions must be established in relation to the statistical behavior of the neutron so that it arrives at a right spot with the proper energy to cause the desired reaction, be it in a bomb or nuclear furnace.

The present device used to control and convert fission energy to useful purposes is known as a reactor, sometimes called a pile. Reactors take many forms and

variations. It has been said that there are as many reactors as there are reactor designers. In general, reactors are divided into three main classes based on the approximate energy level of the neutrons, as thermal (approximately .03 ev), intermediate (approximately 100 ev - 1 MEV), and fast (approximately 1 MEV and over). They are further divided into homogeneous or heterogeneous types and are also further classified as converters or breeders. Heterogeneous reactors have cores in which the fuel is separated from the coolant and/or moderator by cladding or canning. Homogeneous reactors have the fuel and moderator-coolant in solution or as a slurry.

The design and construction of reactors must meet certain conditions. Some of these conditions are quite difficult. Lets take a look at some of them:

1. Neutron Economy - In the fission process depending on the fissionable material used and neutron energy two to three neutrons are produced. One of these is needed to maintain the chain reaction. Some neutrons are absorbed in the structural and other materials of the reactor. Impurities in these reactor materials are often high neutron absorbers and any material used in quantity in reactors must be held to impurity tolerances well below normal commercial ranges. Neutrons also can escape from the active portion of the reactor and provision must be made in the size and other features to hold such losses to a minimum. The fuel itself does not consist only of fissionable material. The remaining or fertile part may have the characteristic of absorbing enough neutrons (producing plutonium in the case of uranium) to stop the chain reaction if the neutrons arrive with improper energy levels. The reactor core must be arranged to prevent the leakage and other undesirable uses or losses of the neutrons.

2. Poisons - In the fission process the fission fragments consist of elements approximately in the middle of the periodic table. Some of these elements are neutron absorbers and sufficient reactivity must be built into the reactor to permit operation over a reasonable period of time before being shut down by this neutron absorption by the fission fragments. Some fission fragments are gases, some are very active chemically and all must be contained in the case of heterogeneous reactors or continuously removed in homogeneous reactors.

3. Moderators - To be an effective moderator the nucleus of the element should be as near the weight of the neutron as possible. It also must be a neutron absorber. The moderator slows down the neutron through multiple collisions until the proper speed or energy level is reached. Several of the lighter elements in the proper form serve this purpose, such as hydrogen and deuterium, also carbon and lithium. Of all, deuterium in the form of heavy water is apparently considered best. To perform its function the moderator must be properly arranged geometrically in relation to the fissionable material.

4. Fuel Elements - The design of fuel elements must contend with a combination of many problems. By and large the fissionable elements are not what would be considered desirable metals. In

heterogeneous reactors which are receiving a large amount of attention the fuel must be cladded (encased or canned). The cladding has several requirements to meet. It must not absorb neutrons. It must be an excellent heat conductor. It must be noncorrosive in the presence of the fuel, moderator, coolant, and fission products. It must not deteriorate under heavy irradiation. Two materials are being widely used as cladding for power reactors, stainless steel and zirconium. Stainless steel has a well established technology while zirconium, which apparently is superior, has just recently come out of the laboratory curiosity class and therefore does not have the advantage of an established technology. In either case their new application still has many problems.

5. Heat Release and Absorption - It has been previously pointed out that the fission of one pound of uranium would release 11,400,000 kwh of heat. This amount occupies a volume of less than two cubic inches, and the release can potentially occur in a very short time. To handle such terrific heat releases the fuel elements and coolant passages must be exceedingly thin to facilitate heat transfer and maintain workable temperatures. This, of course, must be done within the geometry required by neutron behavior.

6. Control - A chain reaction with a small surplus of neutrons proceeds in accordance with the compound interest formula with a compounding period of extremely small fraction of a second. No mechanical control device can act fast enough to continuously control such changes. The reactor must, therefore, be self regulating. This inherent regulation in heterogeneous thermal reactors usually comes about through the fact that as the temperature of the moderator increases its efficiency as a moderator falls off thus slowing down the chain reaction. This effect stabilizes the reactors output at a given load. For coarse control and scram (emergency shut down) control rods, usually of material which are excellent neutron absorbers, are inserted into the active part of the reactor. In the case of thermal reactors these control rods are often made of cadmium or boron. In some cases the control may take the form of adding or subtracting fissionable material, moderator or reflector rather than absorbers. Control is possible at all only because of the delayed neutrons from the fission process. About one percent are delayed one-hundredth second and one-tenth percent are delayed as long as one second.

   The control mechanism must, of course, fail safe under the most adverse conditions. The control rods must move into the reactor core which may require motion through seals which must be completely effective under extremely difficult conditions.

7. Shielding - The fission process produces gamma rays in quantity along with neutrons and beta particles (electrons), etc. Shielding must be provided to enable personnel to come reasonably close to the reactor so it can be observed and controlled. Gamma rays and neutrons which are extremely penetrating provide the largest problem. Shielding is usually divided into two classifications - thermal and biological. Both serve essentially the same purpose, that is, the attenuation of

neutrons and gamma rays. In general the thermal shield prevents excessive heat generation in the biological shield. The heat is developed through the absorption of the neutrons and gamma rays. The thermal shield usually requires cooling and for this reason often employs water which is also an excellent shield material. The other common material is steel.

The biological shield which is the final or outside shield may take many forms. Burying the reactor might be one form. The more common procedure, however, is to use a concrete structure usually made with high density aggregates.

8. <u>Coolants</u> - The extreme heat release rates inherent in the fission process make large demands on the heat transfer agent. In some reactors the coolant and moderator are the same, usually water. In others they are separate. In either case the coolant must not be a neutron absorber and in addition must have good heat transfer characteristics. Coolants being used or considered in addition to water are sodium, NaK (sodium potassium), and fused salts. The liquid metals are receiving considerable attention because of their heat transfer abilities and because they permit high temperatures without high pressures.

Having considered some reactor problems in general, let us turn to specific reactors and see a few of their problems.

It has been previously pointed out that there are potentiality a large number of reactor types; however, five are receiving maximum attention for power purposes. These five have been carefully chosen by the AEC for detailed research to develop what appears to be the best potentials. Experimental versions of all five are being built.

The first in many ways is the pressurized water reactor (PWR). This reactor is being built at Shippingport, Pennsylvania. It is a thermal heterogeneous reactor which uses water under pressure for both moderator and coolant. In these respects it is similar to the Nautilus reactor. Among the major engineering problems of the Shippingport reactor are those associated with the corrosiveness of pure water under irradiation at 500-600° F. and 2000 pounds per square inch pressure. There are also problems of fuel element design and construction. Leak tight construction in the reactor vessel and all parts of the primary circuit are required. Leak tight in the nuclear field implies zero leakage. This reactor may be considered to be in what is called the pilot plant phase. Its nuclear design is considered conservative. The Shippingport reactor is expected to demonstrate reliable power and utility operating procedures. Its fuel elements will require metallurgical processing. This plant is expected to cost about $87,000,000 for a 60,000 KW output. It is being built by Westinghouse. A schematic diagram of the primary parts of the PWR is shown in fig. 1.

The second reactor is the experimental boiling water reactor (EBWR). This reactor is quite similar to the PWR in that it uses water as both moderator and coolant. The difference is that the water is allowed to boil in the reactor and the steam produced is used directly in a turbine. This reactor has the same fuel element, and corrosion problems as the PWR; however, using the steam directly from the reactor simplifies the piping and heat exchange requirements. It also reduces the

pressure in the reactor vessel to that at the turbine throttle. Its problems are concerned with the roughness of operation due to the boiling in the core and the possible carryover to the turbine of radioactive corrosion products, which may make servicing the turbine difficult. Recent studies indicate the radioactive carryover problem may be more imaginary than real. The EBWR is being built by the Argonne National Laboratory. The plant is estimated to cost $17,000,000 for a 5,000 KW electric output. A schematic diagram of this reactor is shown in fig. 2.

The next reactor is the Sodium Reactor Experiment (SRE). This reactor uses sodium for the coolant and carbon for the moderator. Its problems involve the lack of a highly developed technology in the use of sodium as a coolant. Its advantages stem from the sodium coolant which permits high temperatures without pressure in the reactor core and also high heat release rates because of the excellent heat transfer characteristics of the liquid metal. Two heat exchange circuits are used to assure the separation of the radioactive sodium from the water of the steam cycle. This reactor, like all heterogeneous reactors, has the problems of metallurgical processing of the fuel elements. A schematic diagram of this reactor and its cooling circuits is shown in fig. 3. This reactor is being built by Northern American Aviation and is expected to cost about $10,000,000. It will have a 20,000 kw heat output which will be used by a power company turbine installation. The cost does not include the cost of the generation equipment.

The fourth reactor is the Experimental Breeder Reactor II (EBR2). This is a fast reactor and does not use a moderator. As in the case of SRE a double circuit sodium cooling system is used. Since this reactor uses fast neutrons and no moderator, it is very compact. It uses plutonium as the fissionable fuel material. Using the fast neutrons, breeding or the production of fissionable material in excess of that consumed will take place in natural or depleted uranium (U238 with no U235) surrounding the core. The inherent stability of this reactor results from the expansion with heating of the fuel elements. The problems of this reactor are involved with the high heat release in a small volume and also those of the SRE with the liquid sodium coolant. The EBR2 also has the problems of metallurgical fuel element processing. It has, however, because of the use of fast neutrons fewer problems of neutron absorption by structural materials and their impurities. A schematic diagram of EBR2 is shown in fig. 4. This plant is being built by the Argonne National Laboratory at a cost of approximately $40,000,000 and is expected to have an electrical output of 15,000 kw.

The fifth reactor is actually two. The Homogeneous Reactor Experiment (HRE) and the Homogeneous Thorium Reactor (HTR). In both, the fissionable material is in the form of a salt dissolved in water. This solution is piped to a properly designed reactor core where the reaction takes place, then to a heat exchanger and returned to the core. At all times small amounts of the fuel solutions are being withdrawn for processing to remove fission products and then returned to the circuit. The chain reaction is quenched by the geometry of the piping outside the reactor core. The problems of these reactors involve the extreme radioactivity and corrosiveness of the high temperature fuel solution. They have the advantages of assured nuclear stability and safety. Leak tightness of the primary circuit must be absolute. Both the HRE and the HTR are being built by the Oak Ridge National Laboratory and they are expected to cost about $47,000,000. The HRE is to have a heat output of 5,000 KW and the HTR an electrical output of 16,000 KW. A schematic diagram of the HRE is shown in fig. 5.

To encourage commercial development of nuclear power the AEC requested proposals

from industry for the construction of nuclear power plants. The proposals were to specify the required participation by the AEC. In response to this request, the AEC received four proposals and one request for a license. The request for the license specified no AEC assistance other than permission to purchase the supply of special nuclear material.

These proposals and the reactors involved were as follows:

1. Consolidated Edison of New York - For a license only covering a 236,000 KW (electric) unit including an oil fired super heater. This is to be pressurized water reactor similar in most respects to the PWR previously discussed. (License only)

2. Nuclear Power Group - For a 180,000 KW (electric) unit with a boiling water reactor. This unit would be located near Chicago.

3. Atomic Power Development Associates - For a 100,000 KW (electric) fast breeder reactor to be located in Michigan.

4. Yankee Atomic Electric Company - For a 100,000 KW (electric) pressurized water reactor to be located in Massachusetts.

5. Consumers Public Power District of Columbus, Nebraska - For a 75,000 KW (electric) sodium graphite reactor to be located in Nebraska.

It can be seen that all of these proposed power demonstration reactors are based on the experimental reactors previously discussed. The AEC has recently announced that it will proceed further with the proposals of the Nuclear Power Group (Chicago) and the Atomic Power Development Associates (Michigan). The proposals of Yankee Atomic Electric and Consumers Public Power District have not been turned down but it has been indicated that considerable changes will be required to make them acceptable.

The Rural Cooperative Power Association of Elk River, Minnesota has made a proposal to AEC outside of the power demonstration program discussed above for a 22,000 KW (electric) reactor of the boiling water type with a separately fired super heater. Fig. 6 shows a diagram of the reactor portion of the plant.

In addition to the Rural Cooperative Power Association, the following cooperatives or associations of cooperatives are investigating nuclear power through study agreements or access agreements with AEC.

Seminole Electric Cooperative, Inc. Madison, Florida	(Study Group Agreement)
National Rural Electric Cooperative Association Washington, D. C.	(Study Group Agreement)
Kansas Electric Cooperative, Inc. Topeka, Kansas	(Access Agreement)

Minnkota Power Cooperative, Inc. (Access Agreement)
Grand Forks, North Dakota

Corn Belt Power Cooperative, Inc. (Access Agreement)
Humboldt, Iowa

Wolverine Electric Cooperative, Inc. (Access Agreement)
Big Rapids, Michigan

On September 21, 1955, the AEC announced a program of demonstration reactors in the ranges of 5,000 to 10,000 KW, 10,000 to 20,000 KW and 20,000 to 40,000 KW electrical output. This announcement calls for proposals to be in by February 1, 1956. It is quite similar to the original program except that it is limited to the smaller sizes. It is aimed to cover reactors for smaller systems such as municipals and cooperatives. It is also aimed toward reactors for service in the underdeveloped countries of the world.

The announcement will undoubtedly spur much wider action by rural electric systems.

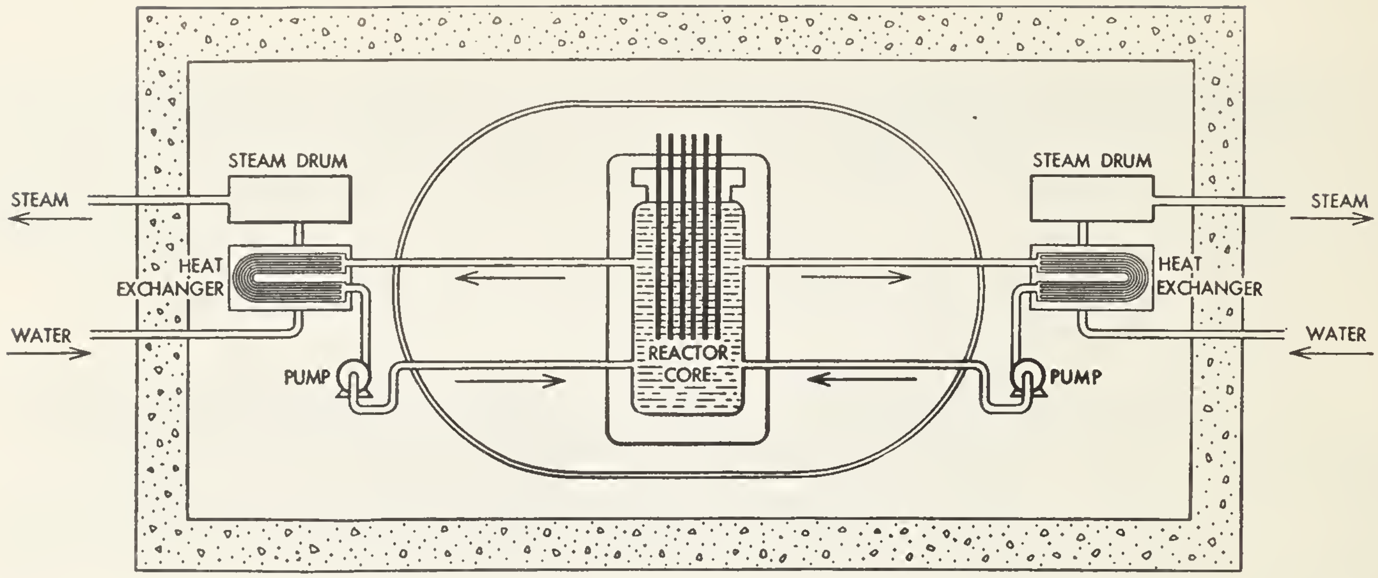

Fig. 1. Pressurized Water Reactor (PWR) Reactor and primary circuits only
Courtesy of "Scientific American"

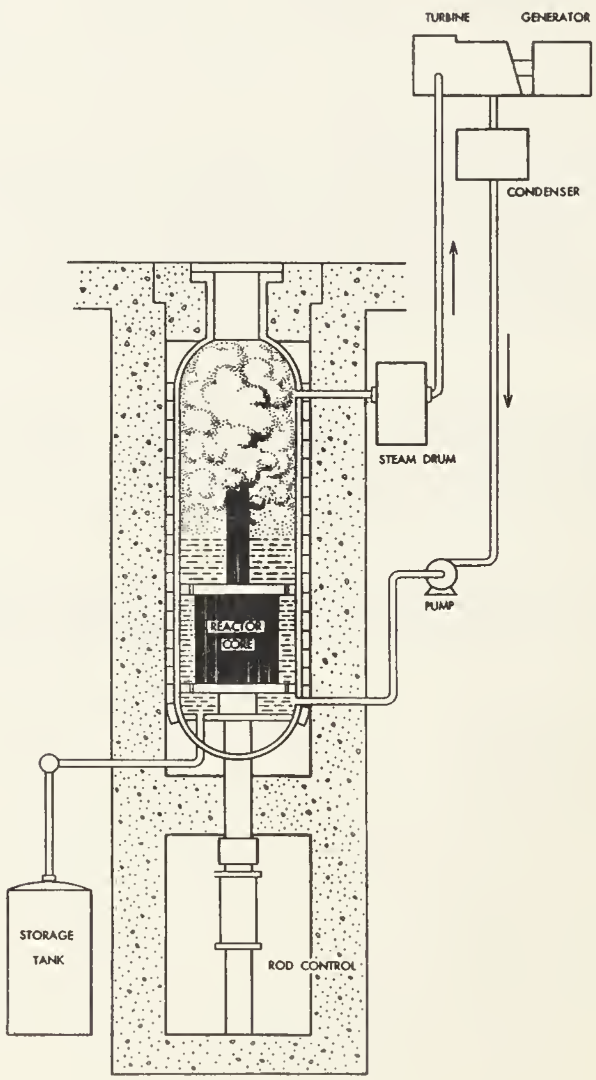

Fig. 2. Experimental Boiling Water Reactor (EBWR)
Courtesy of "Scientific American"

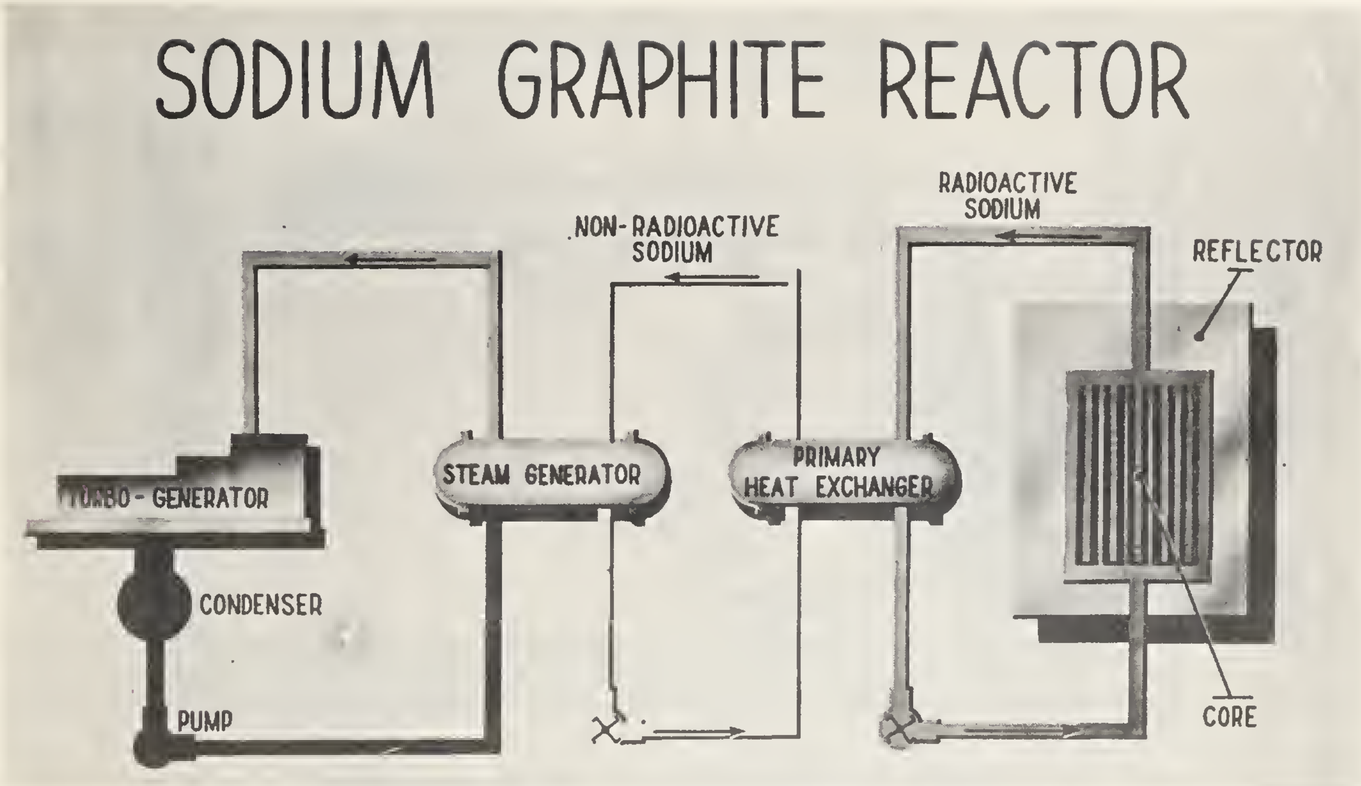

Fig. 3. Sodium Graphite Reactor
(Sodium Reactor Experiment (SRE))
Courtesy of North American Aviation,
Inc.

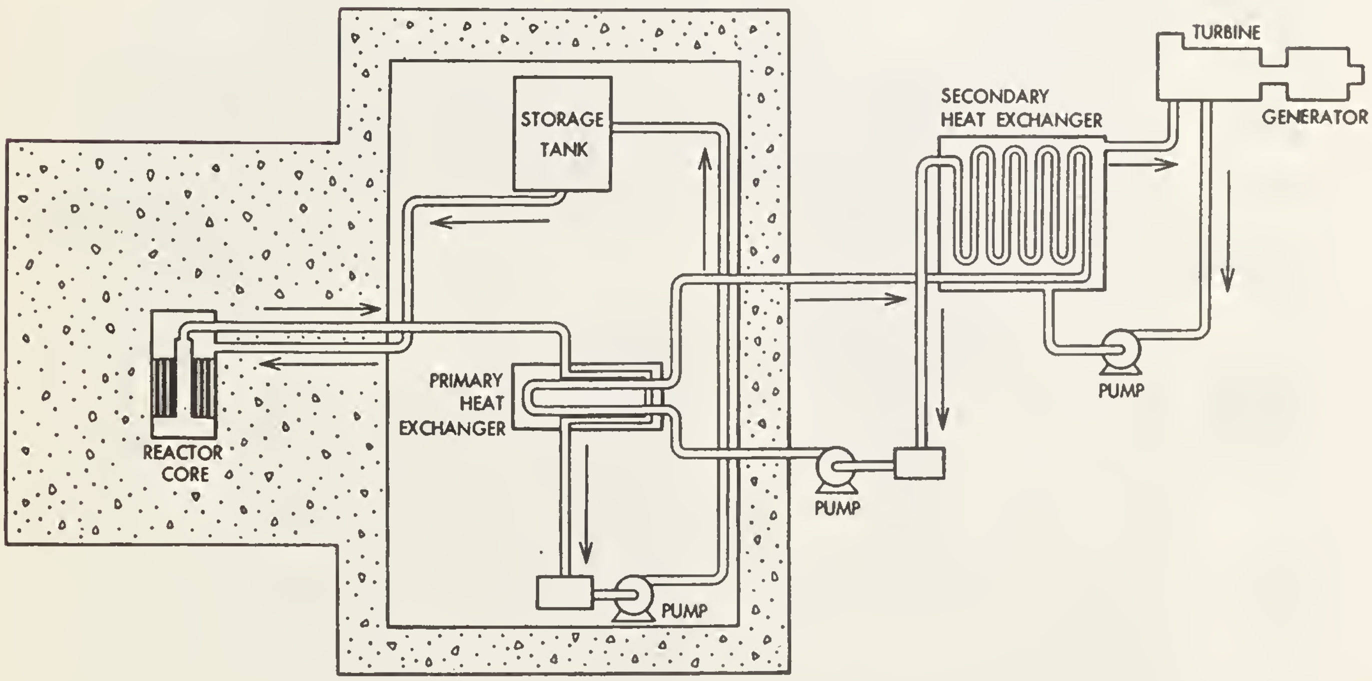

Fig. 4. Experimental Breeder
Reactor II (EBR2)
Courtesy of "Scientific American"

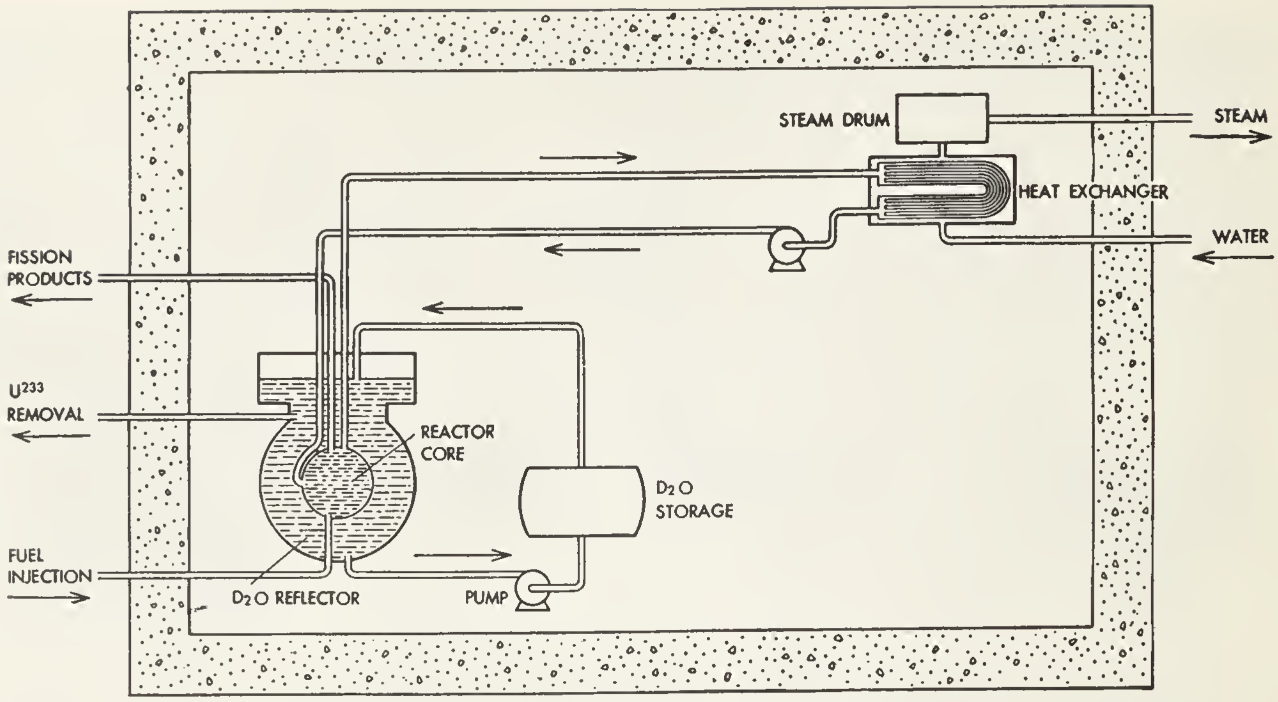

Fig. 5. Homogeneous Reactor Experiment (HTR)
Courtesy of "Scientific American"

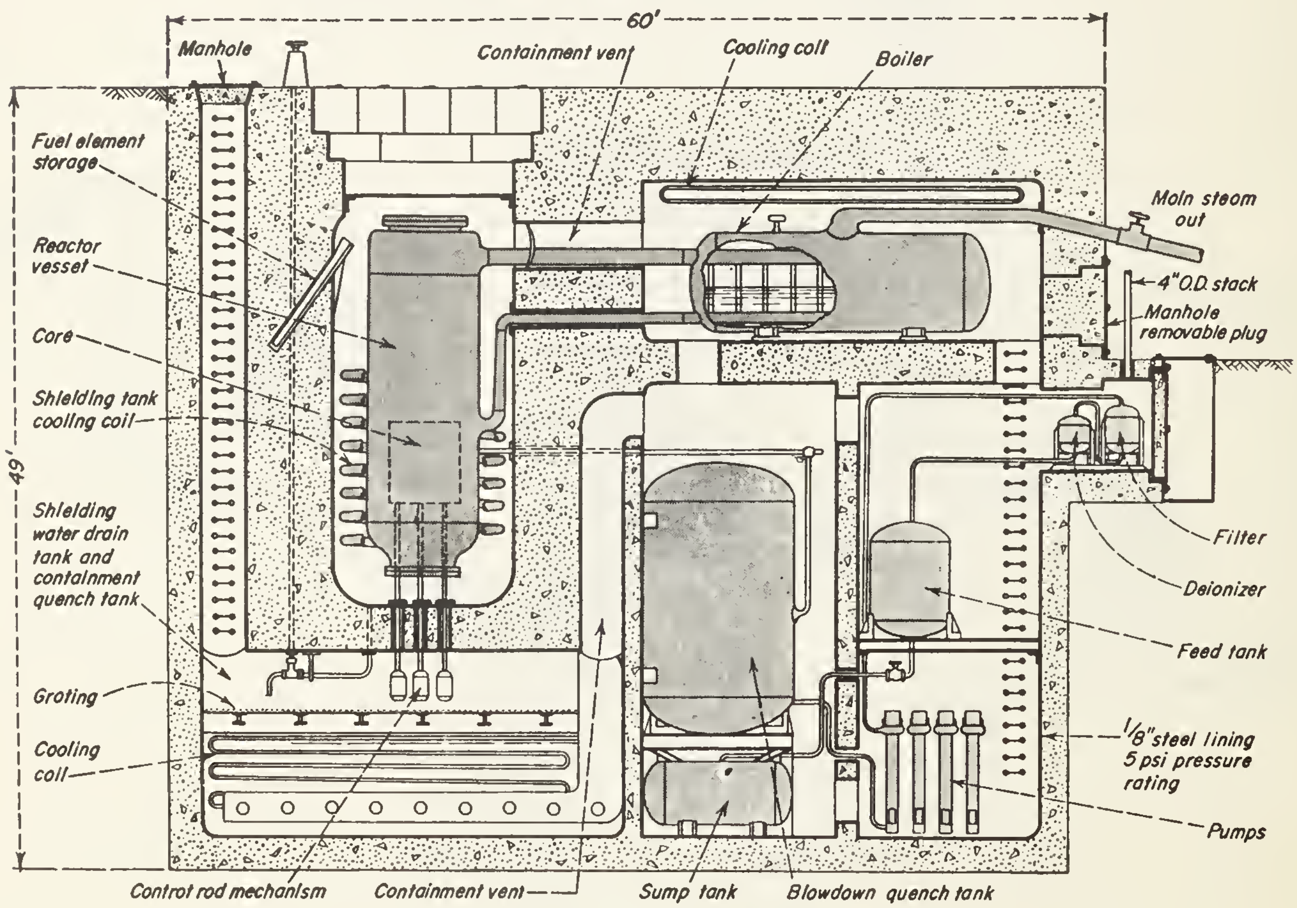

Fig. 6. Rural Cooperative Power Association's Reactor
Courtesy of AMF Atomics, Inc.

FIBERGLASS CROSSARMS AND POLES
(A Motion Picture Film Presentation)

By W. R. Bailey, Director
Research Division
Gar Wood Industries, Inc.
Ypsilanti, Michigan

For Presentation at the 1956 Technical Conference for REA Field Engineers, Saint Louis, Missouri
January 16 - 20, 1956

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Assistant Administrator

FIBERGLASS CROSSARMS AND POLES

W. R. Bailey

In the early fall of 1954 a research project was initiated at Gar Wood Industries, Ypsilanti, Michigan, to investigate the possibility of producing fiberglass poles and crossarms, utilizing mass production techniques.

The first phase of our program was to develop high strength and the most efficient shape capable of utilizing fiberglass oriented in a high strength fashion. A 100,000 psi tensile strength was developed; but to orient that in a fashion so that the material could be efficiently utilized through a small deflection at the top of a mounted pole became a very serious problem. After experimenting with all different forms, a cylindrical tubular section was adopted as the shape to provide the most uniform and efficient pole characteristics.

From this configuration it became necessary to establish data so design criteria could be obtained to build equipment that would be capable of making full-size prototype poles and arms. This data was developed in 2-inch diameter model poles and then projected by mathematical computation to full-size poles. By December 15th full-size prototypes had been made and tested. By January 15, 1955 enough full-size prototypes were made to provide poles and crossarms for a short distribution line of Consumers Power Company in northern Michigan. A movie film showing the loading, installation and testing of the fiberglass poles was prepared for management and engineering personnel in the electrical field to observe.

Our research has indicated that the requirements and standard specifications of the wooden poles and crossarms, as prepared for procurement purposes for the utility companies, were established to maintain a high degree of safety for power lines and communication lines as may be required during all types of weather. The safety factor in the case of wooden poles and crossarms has been placed far in excess of normal requirements to compensate for their irregular contours, unpredictable locations of knots and rapid deteriorating effects of aging and weathering. Consequently, it has been our experience that the pole as shown in the film, which is 11 inches in diameter, 35 feet long and weighs only 150 pounds, will test to approximately Class 6 strength but is capable of fulfilling the performance of a Class 5 wooden pole.

The general data obtained on the fiberglass crossarms and poles to date is as follows:

1. The electrical characteristics of the fiberglass as compared with the wood are 200 to 400 percent better in the dry condition; and in the wet condition the surfaces of the fiberglass retain the same properties, while the surfaces of the wood tend to act as a conductor. By comparison under wet conditions, the electrical properties of wood become so inferior that no numerical comparison can be made to the fiberglass structure. These high electrical characteristics of our fiberglass crossarms and poles should not only reduce the tendencies of electric

flashovers, and in the case of communication lines reduce noise, but should also offer a way to reduce insulators.

2. Greatly improved line performance should be obtained, due to the fact that the electrical impulse strength of this material is so much higher than wood. Also, a great reduction in power leakage should be evidenced during and after heavy rainstorms.

3. Colors may be selected which could offer easy identification of the various utility company poles. This also could be used to provide safety engineers with color combinations to improve highway safety conditions.

4. In addition to the excellent aging characteristics of these fiberglass products, they are resistant to rot, fungus, wood-borers and vermin.

5. The mechanical tests conducted on wooden crossarms and poles indicate that their strength values as taken from a well selected production vary as much as 400 percent. In the case of the fiberglass construction, all tests indicate that our strength values can be maintained to ±5 percent in production.

6. Because of the extremely low weight, shipping costs will be considerably reduced.

7. Lighter weight construction will lend itself to improved methods of erection and handling by utility companies in the field and should be a major factor in reducing the installation cost.

Descriptive comment will be furnished as the film proceeds.